PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Re: Attorney Docket No. 1009.004CIP

In re application of: Mark R. Allen

Serial No.:	09/339,616	Group Art Unit:	2821
Filed:	June 24, 1999	Examiner:	Tuyet Vo
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For: Preferred Embodiment to LED Light String

DECLARATION OF DR. MARK R. ALLEN, Ph.D. SUBMITTED PURSUANT TO 37 C.F.R. §1.132

I, Mark R. Allen, hereby declare:

Introduction

1. I am the inventor named in the above-identified patent application. I have read and understand the Office Action dated August 29, 2000 and all of the references cited therein. The purpose of this Declaration is to traverse the rejections based on Yamuro (U.S. Patent No. 5,941,626) by (1) proving that one of skill in the art would conclude that Yamuro requires a resistor, particularly in view of the prior art; (2) demonstrating, via experiment, that the circuit disclosed by Yamuro, without the resistor, does not work; and (3) explaining the theory behind my invention which distinguishes it from prior art.

Background of Declarant

2. I have a Doctorate degree in Electrical Engineering from the Moore School of Engineering at the University of Pennsylvania (1988). Since then, I have been a high-level

research engineer in the fields of electrical engineering and electronics, including extensive research of LED technology. Currently, I hold the position of Chief Technical Officer for Fiber Optic Designs, Inc., the assignee of the above-identified application.

<u>All Known Prior Art LED Circuits Powered by AC Require Power Conditioning Circuitry</u>

3. Based on my educational background, extensive research in LED technology and professional experience, I know with certainty that, prior to my invention, power conditioning circuitry was thought to be *required* in an LED circuit powered by an AC source. *All* engineering literature that I have reviewed and studied, prior to my invention, *mandates* the use of current-limiting circuitry for diodes, usually in the form of resistance. Whenever conjectured as a possibility in the art, omission of current-limiting circuitry is *always taught to be unstable, and never used.*

4. The prior art exemplifies that current limiting circuitry, such as a resistor, inductor or capacitor, was thought to be required prior to my invention: Reymond (U.S. Pat. No. 5,936, 599) at col. 2, ll. 50-52 states that "a current limiting resistor 28 (a generating resistor) *must be* connected", and at line 57 that "the resistor is the *dominant* factor in determining the LED current." Page 3 of states that "An LED . . . ***requires*** some kind of current limiting". Pages 210 and 211 of <u>Light Emitting Diodes--An Introduction</u>, states that "some means for current limitation ***has to be*** provided". Pages 215 and 216 of <u>Luminescence and the Light Emitting Diode</u> states that "they [LEDs] ***need*** a series resistance to limit the current." Pages 2.18 and 2.19 of Hewlett Packard's <u>Optoelectronics Manual</u>, show that one of ordinary skill in the art would think that Applicant's invention was *not* obvious since removal of current limiting circuitry is taught to harm the LED lamp. These references are examples of engineering literature relied on

by those skilled in the art to build LED circuits. Copies of these references are included as **Exhibit A**.

5. Furthermore, leading LED manufacturers throughout the world, such as Everlight, J & K Super Bright Industrial, Ltd., Yiow Shie Industrial Co., Ltd. and Lite-On Electronics Inc., teach that a resistor *must* be put in series with a power source to (1) protect the LED and (2) provide a stable circuit.

6. Everlight was established in 1983 to produce LED Lamps. The complete history of this highly sucessful LED manufacturer is provided in their 1999 catalog, pertinent portions of which are attached hereto as **Exhibit B**. In 1999, the company had over $130 million dollars (U.S.) in sales. Its management and researchers are "skilled in the art" of LED technology. On page 114 of Everlight's 1999 catalog they clearly teach the use of a protective resistor is necessary and <u>*must*</u> be used.

7. J &K Super Bright Industrial, Ltd. was established in 1986. It has achieved ISO 9002 certification, employs about 1,000 workers, and claims an R&D Division that keeps researching for new technologies and materials. This company also offers assembly aimed at custom design. Its management and researchers are "skilled in the art" of LED technology. On the page entitled "How to Use LEDs" under the section "Preventing Overcurrent", J&K teaches to "put protective resistor in series, not only to prevent overcurrent, but to keep LED in uniform brightness." **Exhibit C.**

8. Yiow Chie Industrial Co., Ltd. was established in 1986, claiming "modern equipment and the most recent R&D." Its management and researchers are "skilled in the art" of

LED technology. Page 83 of its catalog clearly shows the requirement of a resistor for preventing overcurrent. **Exhibit D.**

9. Lite-On Electronics, Inc. is one of the world's largest independent manufacturers of optoelectronic products, including LEDs. Lite-On's 1998-99 Catalog claims that it offers a wide range of reliable and economical opto-electronic design solutions, and is the first IEQC - certified opto products manufacturer in the world, also qualified for ISO 9000 & ISO 1400 certification. Its management and researchers are "skilled in the art" of LED technology. The instructions for "How to Use LITE-ON LED Lamps" clearly teach to "put protective resistors in series" and that the "circuit <u>must</u> be designed so that overvoltage (overcurrent) is not applied to the LED during ON/OFF switching." **Exhibit E.**

<u>Yamuro's Teachings are Consistent with Other Prior Art References Requiring a Resistor</u>

10. Being one of skill in the art, it is my opinion that Yamuro (U.S. Patent No. 5,941,626) clearly teaches that a resistor is required. Yamuro states:

> Since the required power source of 100V is equal to the common source voltage in Japan, the resistance **8** apparently seems unnecessary. However, it is proved from experience that the apparatus is stable in function *by providing the resistance* **8**. *Therefore*, the resistance **8** *is connected* to the circuit shown in FIGS..." (italics added for emphasis).

Yamuro then goes to include, throughout his patent, text and diagrams incorporating a current-limiting resistor in the circuitry without any further reference to any idea or possibility of its omission.

The above *direct quotation* from Yamuro, which is the *only reference made* in his entire patent to the *possibility* of removing his current-limiting resistor, is one that *does not, in any way, advocate or even allow* removal of the resistor. *Exactly the contrary* is taught by Yamuro; that is,

that the *resistance makes the circuit stable, and therefore it is to be used.* Yamuro uses the resistor throughout his patent in the figures and description, which is consistent with the usual design convention of LED circuitry, prior to my invention. Yamuro states the design "...is stable..." by including the resistor. Yamuro does *not* state "...is more stable..." Yamuro directly implies that the circuit is unstable without the resistor. Therefor, the teachings of Yamuro would certainly *always* lead one of skill in the art to include the resistor.

11. Disinterested parties of ordinary skill in the art also would not interpret Yamuro to teach a desire to do away with the resistor. Attached as **Exhibit F** is a letter from Mr. Duane J. Knize, Chief Scientist for the Technology Research Group at Science Applications International Corporation (SAIC). Mr. Knize has over 27 years of engineering experience including circuit and electronic system design and development. In the second paragraph of his letter, Mr. Knize states that "the discussion in column 3 lines 30-40 clearly promulgates a requirement for this resistor" and later in the letter that "it seems clear to me that the author of patent 5,941,626 considered the resistor to be an essential part of his invention."

12. Furthermore, two authors and editors of a number of technical journals, including the editor-in-chief of the *AT&T Technical Journal* for Bell Laboratories, have concluded that lines 30-40 of Yamuro, read *together* clearly teach that a resistor is required. One of these authors and editors, Mr, James M. Murray, President of Timberock USA Company, concluded that the statement in lines 30-33 that "the resistance 8 apparently seems unnecessary" is qualified by and immediately disproved by the statement in lines 34-37 that "[h]owever, it is proved from experience that the apparatus is stable in function by providing the resistance 8. Therefore, the resistance 8 is connected to the circuit shown in FIGS. 1A and 1B". Attached as **Exhibit G** are true and correct copies of (1) a "Letter of Testimony" from Mr. Murray and (2) a

letter from Mr. Bert Vorchheimer, former Editor-In-Chief of the At&T Technical Journal at Bell Laboratories.

__Experimental Evidence Proves that Yamuro Could Not Teach Omitting the Resistor__

13. I performed the experiments described herein. The purpose of the experiments was to demonstrate that the Yamuro circuit, without the resistor, does not work. The experiments confirm my understanding of Yamuro; that is, it does not disclose, teach or suggest an optional circuit design that omits the resistor.

14. Paragraph 7 of the Office Action states **"the teaching supported by line 37, column 3 clearly suggests the removal of the resistor(8)", "[I]f one were to construct figure 1B to be used in Japan, a resistor (8) would have been inherently eliminated as clearly pointed out by this teaching"** and **"given the power situation in Japan as it is suggested under line 37, column 3, one could not help but to construct the circuit without the resistor (8)."** I respectfully disagree.

15. I have constructed three LED circuits, according to the specifications listed in column 3, line 31-43 of Yamuro, to demonstrate that the Yamuro reference could not be read to suggest the removal of the resistor. A fourth LED circuit was constructed using 2.2VDC LEDs.

16. The experiments show that removing the resistor causes the circuit taught by Yamuro to fail. The experiments were videotaped to show the circuit failures. Three copies of the video tape as well as a transcribed copy of the tape is being submitted as **Exhibit H.**

17. Since the Examiner reads Yamuro to suggest that the resistor is optional, the circuit configurations that omit the resistor will be referred to as the "Examiner Option" and the circuits including a resistor will be referred to as the "Yamuro Circuit" or "Yamuro Design".

18. Each circuit was constructed using 2-volt DC LEDs, as specified by Yamuro at column 3, line 31. It is well known in the industry that LED voltage specifications are calculated under DC operating conditions. Thus, I will refer to the LEDs disclosed by Yamuro, as well as those used in the experiments as "2-volt DC" LEDs.

19. The specific LED's used were manufactured by Ledtech, Inc. and bear part number LT1833(4)-81-M1. The LEDs produce a 20 mA nominal DC current. Attached as **Exhibit I** are the specification sheets for these LEDs.

20. Each light string circuit will be referred to as a separate "case". Since I did not have access to a 100VAC source, as called for in Yamuro, the circuit of cases 1 and 3 assume an AC source voltage of 110VAC, and the circuit of cases 2 and 4 assume an AC source voltage of 120VAC. Typical U.S. household source voltage varies between 110VAC and 120VAC. Thus, experiments were conducted assuming both conditions to ensure the validity of the conclusions drawn from the experiments.

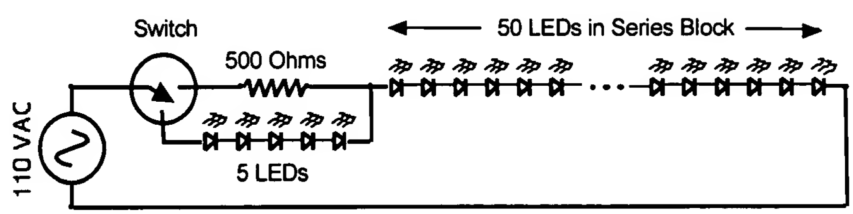
21. To compensate for using source voltages that are 10 VAC and 20VAC above the 100VAC called for by Yamuro, five (5) 2-volt DC LEDs were added to cases 1 and 3, and ten (10) 2-volt DC LEDs were added to case 2. To demonstrate both the Examiner's Option (resistor optional) and Yamuro's Design (resistor required), the circuit in cases 1 and 2 is connected through a switch to either a resistor or a number of LEDs. In one position, the resistor completes

the circuit according to my understanding of Yamuro (Yamuro Design). In a second position, LED's are substituted for the resistor, as suggested by the Examiner (Examiner's Option).

22. The value of the resistor in all cases is calculated according to one of the examples provided in Yamuro at column 3, lines 40-43, which states "50 or less LED lamps **4**, for example 45 or 40 LED lamps, can be connected to the light emitting unit **6**. In this case, the resistance value corresponding to the potential difference from the power source **9** is set as the resistance **8**." I selected Yamuro's 45 LED example for cases 1 and 2, then added five (5) 2-volt DC LEDs to the circuit of case 1 and ten (10) 2-volt DC LEDs to the circuit of case two, to equate the 100VAC source voltage in Japan to the assumed 110VAC and 120VAC source voltages in the U.S., respectively.

<u>**Experiment Case #1**</u>

23. For case 1, fifty (50) 2-volt DC LEDs were used, which accounts for 100VAC of the assumed 110VAC source, leaving 10VAC to be compensated by either (1) a resistor when the switch is in the first position, or (2) a number of LEDs when the switch is in the second position. In the first position, a resistor value of 500 Ω was calculated by dividing 10VAC by the 20 mA specified nominal current produced by the LEDs. In the second position, the number of LEDs was calculated by dividing 10VAC by 2-volts (the specified LED voltage) yielding five (5) LEDs. The circuit of case 1 is schematically represented as follows:



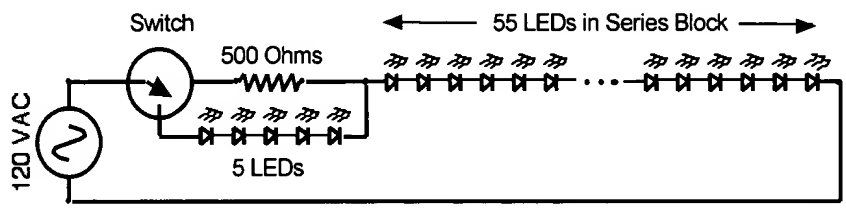
Case 1: 110 VAC

24. The experiment of case 1 was conducted by placing the switch in the first position, then plugging the circuit into a household receptacle. This configuration mirrors the Yamuro Design. The circuit was stable and the resistor became quite hot. I agree that Yamuro, as well as a number of other prior art references made of record in this case, teach this circuit (i.e. Hewlett Packard's Operational Considerations for LED Lamps and Display Devices notes that a resistor must be used to maintain circuit stability). *See* **Exhibit J**. The switch was then moved from the first position to the second position, replacing the resistor with an equivalent number of LEDs. This circuit represents the Examiner's Option. This circuit considers the Examiner's statement that Yamuro "clearly suggests the removal of the resistor **8**". It is an example of the circuit that the Examiner contends is "operatively stable" in paragraph 7 of the Office Action (except of course for the five (5) LEDs added to this experiment to account for the difference in source voltage). When the switch was moved to the second position, the LEDs immediately dimmed, indicating that the circuit was being stressed. The LEDs then quickly began to fail until the entire LED string failed.

25. Based on the observed results of the experiment of case 1, I conclude that the Yamuro circuit without the resistor is inoperable. Therefore, Yamuro could not be read to suggest the removal of the resistor.

Experiment Case #2

26. For case 2, fifty-five (55) two (2) volt DC LEDs were used, which accounts for 110VAC of the assumed 120VAC source, leaving 10VAC to be compensated by either (1) the resistor when the switch is in the first position, or (2) a number of LEDs when the switch is in the second position. Similar to calculations performed for case 1, the value of the resistor connected to one side of the switch was 500 Ω and five (5) LEDs were connected to the other side of the switch to account for the 10VAC. The circuit of case 2 is schematically represented as follows:



Case 2: 120 VAC

27. The experiment of case 2 was conducted in the same fashion as case 1 with nearly identical results. With the switch in the first position, the circuit was stable and the resistor was very hot. With the switch in the second position, the lights immediately dimmed, indicating that the circuit was being stressed; then the LEDs slowly began to fail until the remaining LEDs all failed virtually simultaneously. The only difference between case 1 and 2 was that the circuit of case 2 took slightly longer to fail when the resistor was removed, but the circuit was nonetheless highly unstable.

28. Based on the observed results of the experiment of case 2, I conclude that the Yamuro circuit without the resistor is inoperable. Therefore, Yamuro could not be read to suggest the removal of the resistor.

Experiment Case #3

29. The circuit of case 3 was similar to case 2, however the switch and additional LEDs were omitted from the circuit. Fifty-five (55) 2-volt DC LEDs were connected in series to a 500 Ω resistor. Assuming an AC source voltage of 110 VAC, the circuit was stable and performed as expected, **due to the resistor**.

30. The resistor was then physically removed from the circuit to test the Examiner's assertion in paragraph 7 of the Office Action that "the teaching supported by line 37, column 3 clearly suggests the removal of the resistor(8)". The circuit, when connected to the AC source, failed immediately. In fact, in the video demonstration of this particular experiment, one can hear the LEDs "pop" when the circuit is connected to the AC source.

31. Based on the observed results of the experiment of case 3, I conclude that the Yamuro circuit without the resistor is inoperable. Therefore, Yamuro could not be read to suggest the removal of the resistor.

Experiment Case #4

32. The circuit of case 4 was identical to the circuit of case three, except 2.2-volt DC LEDs were used. Fifty-five (55) 2.2-volt DC LEDs were connected in series to a 500 Ω resistor. This circuit duplicates the example in Yamuro where 50 2-volt DC LEDs + a resistor are used at 100VAC. As expected, **due to the presence of the resistor in the circuit**, the circuit was stable. The resistor was then removed from the circuit leaving fifty-five (55) 2.2-volt DC LEDs connected in series to the electrical plug. According to the Examiner's reading of Yamuro, that an LED circuit can be stable without the resistor if sum of the specified LED DC voltage for each

LED in the circuit matches the AC source value, this circuit should be stable up to 121VAC (2.2-volts x 55 LEDS). However, the circuit failed almost immediately when connected to the AC source.

33. Based on the observed results of the experiment of case 4, I conclude that the Yamuro circuit without the resistor is inoperable. Therefore, Yamuro could not be read to suggest the removal of the resistor.

Summary of Experimental Results

34. A chart summarizing the results of the experiments is provided below:

Case	**Voltage**	**Resistor**	**LEDs**	**Description**	***Result***
1	110 VAC	500 Ω	50 2-volt DC	Yamuro Design	*Stable, Works*
1	110 VAC	None	55 2-volt DC	Examiner "Option"	*Fails Quickly*
2	120 VAC	500 Ω	55 2-volt DC	Yamuro Design	*Stable, Works*
2	120 VAC	None	60 2-volt DC	Examiner "Option"	*Fails Quickly*
3	110 VAC	500 Ω	55 2-volt DC	Yamuro Design	*Stable, Works*
3	110 VAC	None	55 2-volt DC	Examiner "Option"	*Fails Quickly*
4	120 VAC	500 Ω	55 2.2-volt DC	Yamuro Design	*Stable, Works*
4	120 VAC	None	55 2.2-volt DC	Examiner "Option"	*Fails Quickly*

35. From these experiments and several others I conducted using LEDs from different manufacturers yielding the same results (which are not set forth herein), I conclude that any LED circuit that is designed by matching the sum of the DC specified voltages of all of the LEDs in

the circuit to the AC source voltage will be unstable and fail. Accordingly, the mere substitution of LEDs for a resistor using LED voltage specifications which are always specified under *DC operating conditions* leads to circuit instability and inevitable circuit failure.

The Theory Behind Applicant's Invention that Distinguishes it from the Prior Art

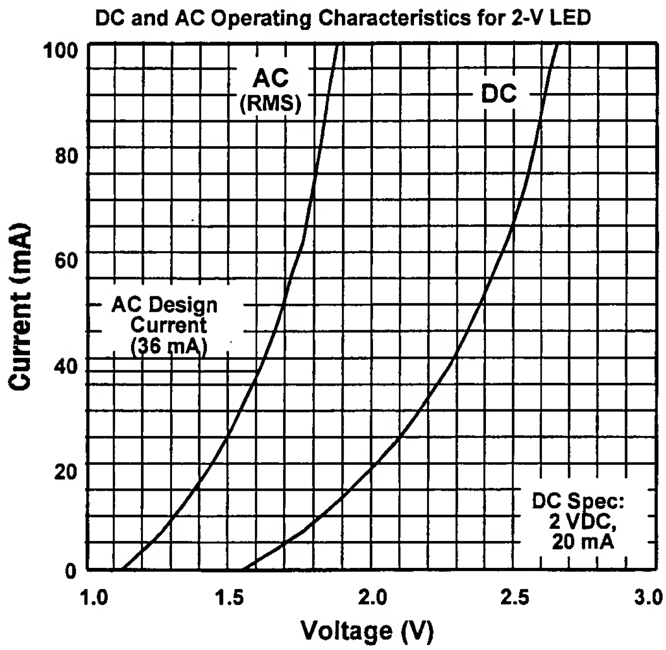
36. LED circuit theory is based on DC power and the fact that LEDs, being diodes, have a highly nonlinear current-versus-voltage characteristic curve; unlike a resistor whose current-versus-voltage characteristic curve is linear. LEDs are "current driven" devices which fail if the applied DC voltage is too high. As such, the prior art teaches that all LED circuits *require* an auxiliary circuit that limits input current as voltage is increased. Limiting the input current as the voltage increases stabilizes the LED circuit by *linearizing* its current-versus-voltage characteristic curve. The simplest auxiliary circuit is a single impedance element. For DC power, the impedance element is a resistor.

37. It is known that LED circuits can be powered by pulsed DC or AC power, in addition to steady-state DC power. However, these different sources of power do not change the fundamental fact that diodes are current-limited devices. Thus, even the most recent prior art teaches that LED circuits *require* at least one impedance element. In the case of AC power, the impedance element may be a resistor, or a reactive element such as a capacitor or inductor. Since the reactance of a capacitor or inductor is constant at a steady frequency (such as 60Hz), the reactive element behaves like a resistor and therefor, can be substituted for a resistor. US Patent 5,936,599 to Reymond shows such substitution.

38. To arrive at my invention, I challenged the assumptions that stem from traditional LED circuit theory mentioned above, including the assumption that an impedance element is required to stabilize an LED circuit driven by AC power. Knowing that LED performance

specifications are provided under DC operating conditions, I discovered that the DC specifications can not be used to gauge the performance of LEDs *under stable AC operating conditions* because of the nonlinear current-versus-voltage characteristic of diodes. With AC input, the LEDs are off over half the time while the voltage is below some positive threshold value (reverse bias). Then, as the voltage increases beyond RMS to peak value and falls back again, diode current varies accordingly in a nonlinear fashion. I discovered that, for AC power, the average (RMS) LED current is much larger than that which would be obtained if the LED were powered by a DC waveform whose voltage is equal to the average (RMS) voltage of the AC waveform. In other words, if the *DC specified* LED voltages are used to match the AC source voltage in the LED circuit, the resulting LED current will be much larger than desired, and the circuit will be unstable and fail. The experiments I performed (described above) fully support this theory.

39. To arrive at the claimed invention, I measured LED current at varying *AC voltages* for a particular LED to create an *AC operating curve* (i.e. I-V characteristic curve) for the LED. The graph below is an example of a *DC operating curve* for a 2-volt DC LED (typically provided by the manufacturer) and the corresponding *AC operating curve* for the same LED:

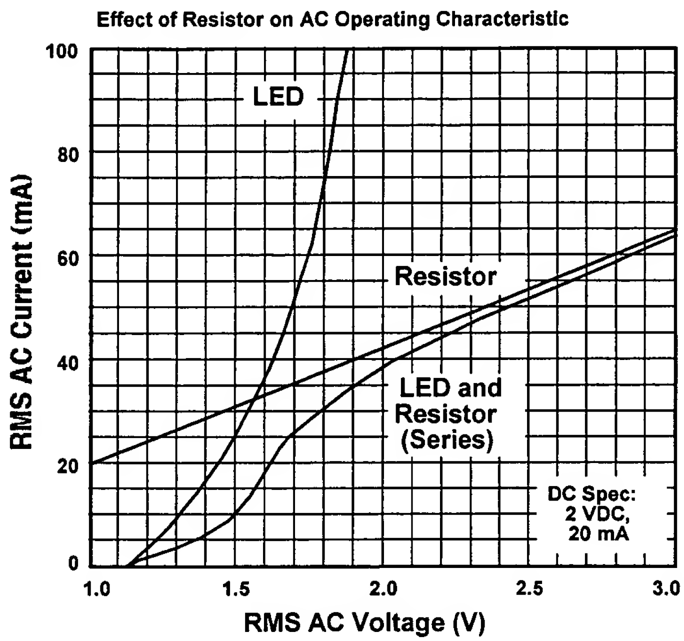


As you can see from the graph, 2-volts on the horizontal axis does not cross the AC operating curve below 100mA, which is known to be the typical maximum operating current (Imax) of an LED. This observation is significant and explains the failures in the experiments performed above. That is, the current produced by matching 55 2-volt DC LEDs to a 110 VAC source exceeds the maximum operating current of the 55 LEDs, thereby causing the LEDs to fail.

40. According to my invention, the *AC voltage* of the LEDs are matched to the AC source. Thus, the current produced by the LEDs falls within a range that is acceptable and stable. For example, from the curve, any value of current between the turn-on voltage (or threshold voltage) of the LED and the maximum voltage (or voltage at which the LED fails) can be

selected as the *AC operating current* and the corresponding *AC operating voltage* of the LED can be read. If the AC source voltage of an LED circuit is 110VAC, fifty-five (55) 2-volt *AC* LEDs can be connected in series to the source and be stable.

41. The effect of a resistor on this AC operating curve is shown below:



I created this curve to show how the resistor linearizes the AC current-versus-voltage characteristic curve of an LED. However, I discovered that the resistor could be eliminated by reading the AC curve *directly* and selecting an operating voltage at a stable point on the AC curve. For example, according to the example provided, a 2-volt DC LED is stable at 1.6 VAC. Thus, an LED circuit powered by a 110 VAC source would be stable if it comprised 69 of these 1.6 VAC LEDs.

42. A brief videotaped presentation detailing the theoretical distinction between *AC characterized* and *DC characterized* LEDs follows the experiments on the videotape submitted as **Exhibit H**.

43. I inspected a set of light strings displayed by Excellence Optoelectronics, Inc. at an electronic show in Taipei from October 9-12, 2000. The light set was identical to my a light string according to my invention and built according to the teachings of my application for patent.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on Feb 27, 2001.

Mark R. Allen, PhD

Mark R. Allen
Chief Technical Officer
Fiber Optic Designs, Inc.

LIGHT EMITTING DIODES

AN INTRODUCTION

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7 APPLICATIONS

7-1 General aspects

Because light emitting diodes are solid state, semiconductor light sources, they have some specific properties in common with other semiconductor devices like transistors or integrated circuits. Some general features of LEDs and other semiconductor devices are small size, low weight, high mechanical stability, low temperature sensitivity, high reliability, long operating lifetime, and last but not least, low price. As electrical devices, LEDs are characterized by low operating voltage, medium current, and high speed. From an optical point of view, the most important properties of LEDs can be summarized as follows: LEDs are active emitters of nearly monochromatic light with highly saturated colors.

From this set of properties some specific fields of application can be derived, which are treated in detail in the following parts of this chapter. Only a few general remarks will be made here. LEDs are mostly used at the periphery of electronic equipment of all kind. Interfacing LEDs to electronics is especially easy, because their driving requirements can be easily fulfilled by standard transistors and integrated circuits. This property is decisive for the bulk of LED applications. Typical examples are status indicators, displays for entertainment electronic equipment, and displays for measuring equipment. LEDs are also preferred to other display tech-

nologies in rough environments and where high reliability is imperative.

On the other hand, the properties of LEDs define also the limits of their applicability. For example, LEDs are not well suited for general illumination purposes, because their brightness is still inferior to other light sources, and because white light can hardly be achieved (blue LEDs are less efficient than red, yellow and green devices), but is required for color-neutral illumination. LEDs are also rarely used in battery operated equipment, where power consumption is a critical factor. Here liquid crystal displays (LCD) are dominating. The relatively high power consumption, and consequently, power dissipation of LEDs renders also the realization of high resolution, flat LED screens more difficult (see section 7-3-4). For color picture displaying, the inferior brightness of blue emitters is another limitation. Other competing flat screen technologies like LCDs or plasma displays also have difficulty in displacing the cathode ray tube, which is well developed. It offers rather high performance at quite low cost.

7-2 Driving of LEDs

7-2-1 Current limiting

The I-V characteristics of LEDs are those of normal pn diodes: in the forward direction, which is the normal operating mode, the current remains rather small until the voltage amounts to approximately E_g/e, which is about 1.9 V for red LEDs, 2.0 V for orange, 2.1 V for yellow, and 2.2 V for green. Around these voltages the current rises exponentially (see chapter 1). Because the brightness of an LED is determined by the current flowing through the device, it is the

current which has to be defined during operation. If an LED is driven by a voltage source, its brightness is very sensitive to small voltage fluctuations, due to the steep I-V characteristics. Therefore, some means for current limitation has to be provided. Two examples for current definition in LED circuits are shown in Fig. 7-1. The simplest possibility is a resistor in series to the LED (Fig. 7-1, left). Here the current through the LED (I_{LED}) is defined by the intersection of the LED characteristics with the straight line given by (operating voltage minus LED voltage) divided by resistance, which is (5 volts-V_{LED})/150 Ω in the example shown. As can be seen easily, the LED current is now far less sensitive against voltage changes. In most practical applications the value of the resistor can be calculated using the simple formula:

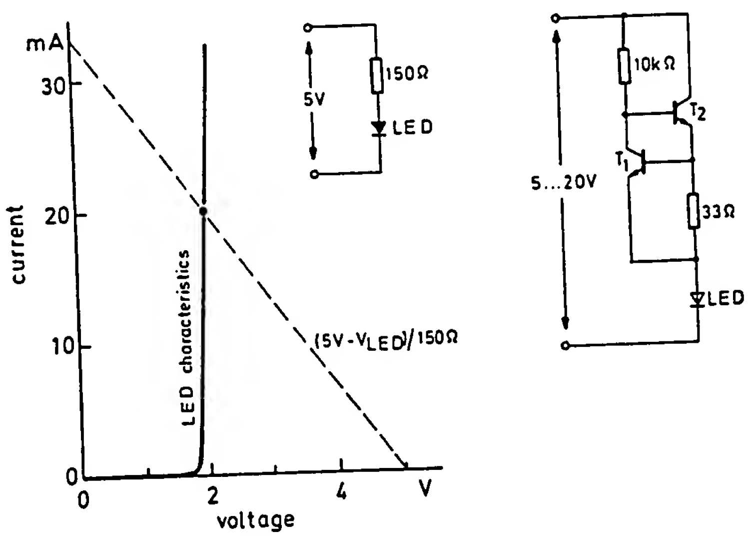

Fig. 7-1 Methods of control of LED current, left: LED with series resistor, determination of working point, right: LED with constant current source for approximately 20 mA.

$$R = (\text{operating voltage} - 2\text{ V})/\text{LED current} \qquad (7\text{-}1)$$

because the forward voltage required for a normal operating current is roughly 2 volts for all types of LEDs.

If large voltage variations are to be expected, LEDs are driven best using a constant current source. For this purpose integrated circuits are available which are supplied by several manufacturers. A simple constant current source can also be realized with two transistors and two resistors as shown on the right hand of Fig. 7-1. This circuit controls the LED current via the voltage drop along the 33 Ω resistor, which is 0.66 V at 20 mA output current. If the current increases, the transistor T_1 becomes more conducting, thus diminishing the current flowing into the base of the transistor T_2. Therefore, the output current is decreased again. The value of the second resistor is determined by the minimum voltage to be expected and the base current necessary to drive T_2. In the example shown it is assumed that at least 2 V are available at this resistor (5 V minus LED voltage minus collector emitter voltage of T_2), and that 0.2 mA are sufficient to cause an output current of 20 mA, i.e. the current gain of T_2 should be at least 100. The upper voltage limit is given by the power dissipation in T_2 which is roughly 20 V times 20 mA or 0.4 W.

7-2-2 Multiplex operation

Because the light output of an LED is proportional to the operating current over a wide current range, LEDs can be driven by pulses instead of continuous current. The apparent brightness is then given by the average current. Some LED types even exhibit a superlinear current-light relationship, so that a net gain in brightness results in pulsed operation. This property is widely used in time multiplex operation of

Light-emitting diodes

A.A. BERGH
and
P.J. DEAN

CLARENDON PRESS · OXFORD
1976

Oxford University Press, Ely House, London W. 1

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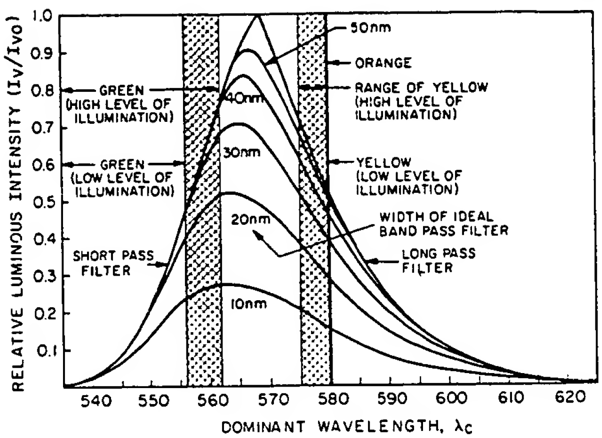

Fig. 7.13 Relative luminous intensity of a yellow–green GaP:N lamp as a function of dominant wavelength, using a series of ideal cut-off filters and a series of narrow band pass filters [9, 10].

can be shifted either to the green or to the yellow–orange. The data in Table 7·3 demonstrate, however, that the over-all lamp performance is not necessarily degraded to the same extent as the brightness of the lamp. With the green colour, for example, both a short pass and a narrow band pass filter yield a performance figure (T^2/T_a') greater than unity, indicating that the loss in brightness is compensated by the increase in contrast. Simultaneously, the colour discrimination in white ambient light also improves.

7.1.3. *Basic LED drive circuits*

The operation of LEDs is regulated by the forward current–voltage characteristics of semiconductor diodes.

$$I_F = I_0 \exp(qV_F/nk_BT) \quad , \tag{7·9}$$

where the value of n is usually in the range of 1·5 – 2·0. The light emission characteristics of the devices follow a similar expression (except for very low current densities),

$$\Phi \propto \exp(qV_F/nk_BT) \; , \tag{7·10}$$

with $n = 1$ until the light-emitting centres saturate (1 – 5 A cm^{-2} only for red GaP:Zn,O). As a result the light emission is usually superlinear with increasing current, and hence it is advantageous to use low duty cycle pulsed drivers.

The turn-on voltage is governed by the built-in potential of the device V_{bi}, which in turn depends on the energy gap of the semiconductor and the distance of the Fermi level from the conduction and valence bands

$$qV_{bi} = E_g - (qV_n + qV_p) \quad . \tag{7.11}$$

Typical operating voltages are 1·2 V for GaAs, 1·7 V for red $GaAs_{1-x}P_x$, and 2·0 V for GaP devices. The temperature-dependence of the forward voltage is similar for all devices, approximately -2 mV $°C^{-1}$.

LEDs must be biased from a constant current source. In case of a constant voltage source this can be approximated by placing a resistor in series with the power supply, as shown in Fig 7·14. The resistor, usually a silicon chip,

TABLE 7·3
Calculated lamp performance as a function of ideal filter parameters (incandescent light at 2560 °C)

λ_1 (nm)	λ_2 (nm)	Type of filter	Colour †	λ_c (nm)	T ‡	T_a' §	T^2/T_a'
540	IR	Long pass	Y–G	569	0·993	0·805	1·22
550	IR		Y–G	570	0·945	0·728	1·23
560	IR		Y–G	574	0·751	0·642	0·88
570	IR		Y	582	0·479	0·550	0·42
UV	570	Short pass	G	557	0·521	0·450	0·60
UV	580		G	561	0·745	0·544	1·02
UV	590		G–Y	565	0·878	0·637	1·21
UV	600		Y–G	567	0·944	0·720	1·24
UV	610		Y–G	568	0·975	0·795	1·20
530	560	Band pass	G	551	0·248	0·228	0·27
540	570		G	557	0·514	0·255	1·04
550	580		G–Y	563	0·690	0·273	1·74
560	590		Y–G	570	0·630	0·279	1·42
570	600		Y	578	0·423	0·270	0·66
580	610		Y	587	0·231	0·250	0·21

† Y: yellow; G: green.

‡ T: relative loss of luminous output due to filter.

§ T_a': double pass luminous transmittance of filter to the ambient illumination.

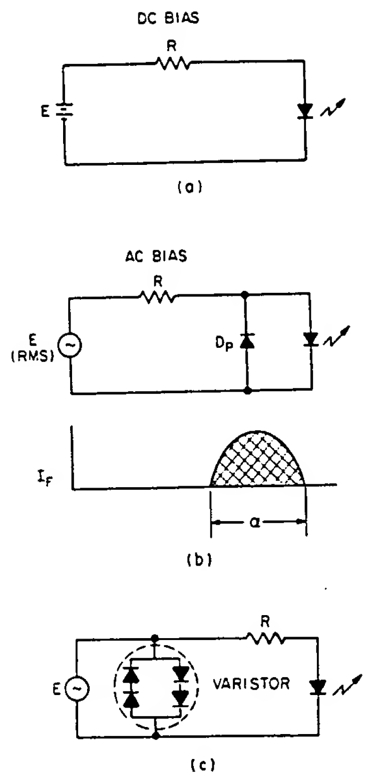

Fig. 7.14 Basic LED drive circuits using a constant voltage source.

can be built into the LED package as shown in Fig 7·6 (c). The value of the desired resistance R is simply given as

$$R = (E - V_F)/I \quad , \tag{7·12}$$

where E represents the applied voltage.
For the a.c. operation the average forward current is

$$I_F = \frac{E\sqrt{2}}{\pi R} \int \left(\cos x - \frac{V_F}{E\sqrt{2}}\right), \tag{7·13}$$

where pulse width a is given by

$$a = \cos^{-1}(V_F/E\sqrt{2}) . \tag{7·14}$$

The rectifier diode D_p is optional for LEDs with low reverse breakdown voltages.

For a one-sided abrupt junction such as a diffused $GaAs_{1-x}P_x$ diode, the breakdown voltage is given as

$$V_B = \frac{\epsilon_s \mathcal{E}_m^{\ 2}}{2q} (N_B)^{-1} \quad , \tag{7·15}$$

where ϵ_s is the semiconductor permittivity, $\mathcal{E}_m$ the maximum field, and N_B the ionized background impurity concentration of the lightly doped side of the junction. If the potential of the voltage supply is such that $E(\mathrm{RMS}) > B_V/\sqrt{2}$ (B_V can be as low as 3 V), excess reverse current will reduce the efficacy of the LED.

The maximum flow of current to the LEDs under variable drive conditions can be limited with varistors as shown in Fig 7·14 (c). Under low current condition, the varistor draws no current. At higher currents, as the voltage across the varistors increases, the fraction of current through the varistor steeply increases. An important feature of this circuit is its lower vulnerability to current surges. Most of the energy from a transient pulse is absorbed by the varistors, which are generally more rugged than the LEDs.

Constant current drive for the typical and most common on or off indicators is provided by saturated transistor switching, as shown in Fig 7·15. If the device is connected in series with the transistor circuit Fig 7·15 (a), the current supplied to the LED when the switch is closed is given as

$$I_F \sim (V_{cc} - V_{SAT} - V_{F,LED})/R. \tag{7·16}$$

For applications where it is desirable to minimize the current variations in the power supply in order to avoid regeneration currents in associated circuits, shunt saturated switching is more desirable (Fig 7·15 (b)). When the switch is open, the current supplied to the LED is

$$I_F \sim (V_{cc} - V_{F,LED})/ R. \tag{7·17}$$

Finally, in applications where the light output of the LED must be modulated, the drive transistors operate in the active mode with the LEDs connected in series with the collectors. For a high impedance input such as shown in Fig 7·15(c), the input current of the transistor is given as

$$I_{BE} \approx E/h_{FE}R, \tag{7·18}$$

and the current supplied to the LED is given as

$$I_F = (E - V_{BE})/R. \tag{7·19}$$

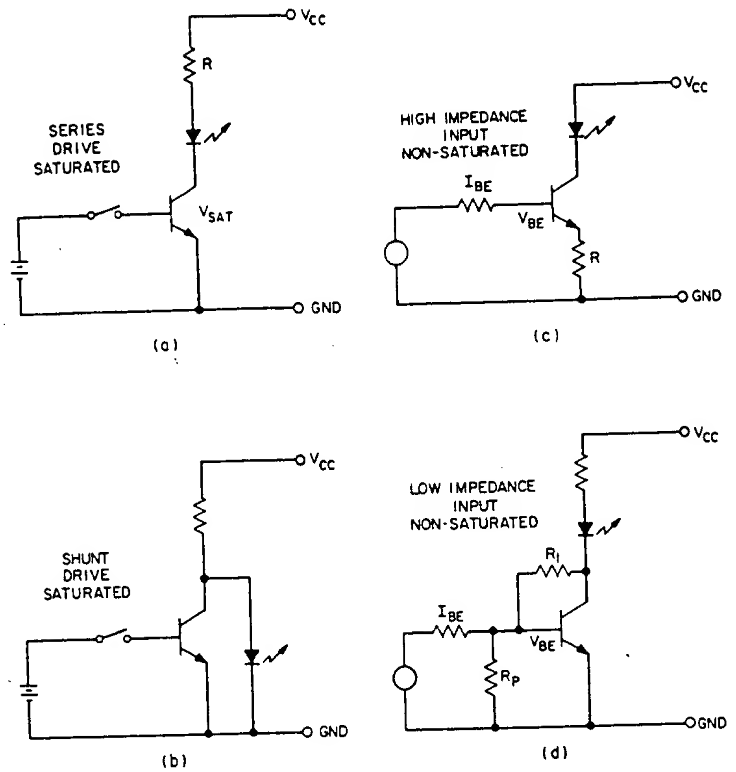

Fig. 7.15 Constant current transistor drive circuits for LEDs.

In case of a low impedance input (Fig 7·15 (d)), the corresponding expression is given as

$$V_{\mathrm{EB}} \approx I_{\mathrm{BE}} R_{\mathrm{p}} / h_{\mathrm{fe}} (R_2 / R_1) \tag{7·20}$$

and

$$I_{\mathrm{F}} \approx (R_1/R_2)\, I_{\mathrm{BE}}. \tag{7·21}$$

7.2. LED displays

The basic formats for LED displays are shown in Fig 7·16. The seven segments and the 3 x 5 array are usually used to display numbers from 0 to 9, although they are capable of displaying some upper case letters (A,B,C,D,E,F,G, H,I,J,L,O,S,U) and a few lower case letters (b,c,d,h,i,l,n,o,r,u). For numeric displays the seven-segment format is the most widely used, while for

LUMINESCENCE AND THE LIGHT EMITTING DIODE

The Basics and Technology of LEDS and the Luminescence Properties of the Materials

by

E.W. WILLIAMS
I.C.I., Corporate Laboratory, Runcorn, Cheshire

and

R. HALL
Thorn Lighting Limited, Leicester

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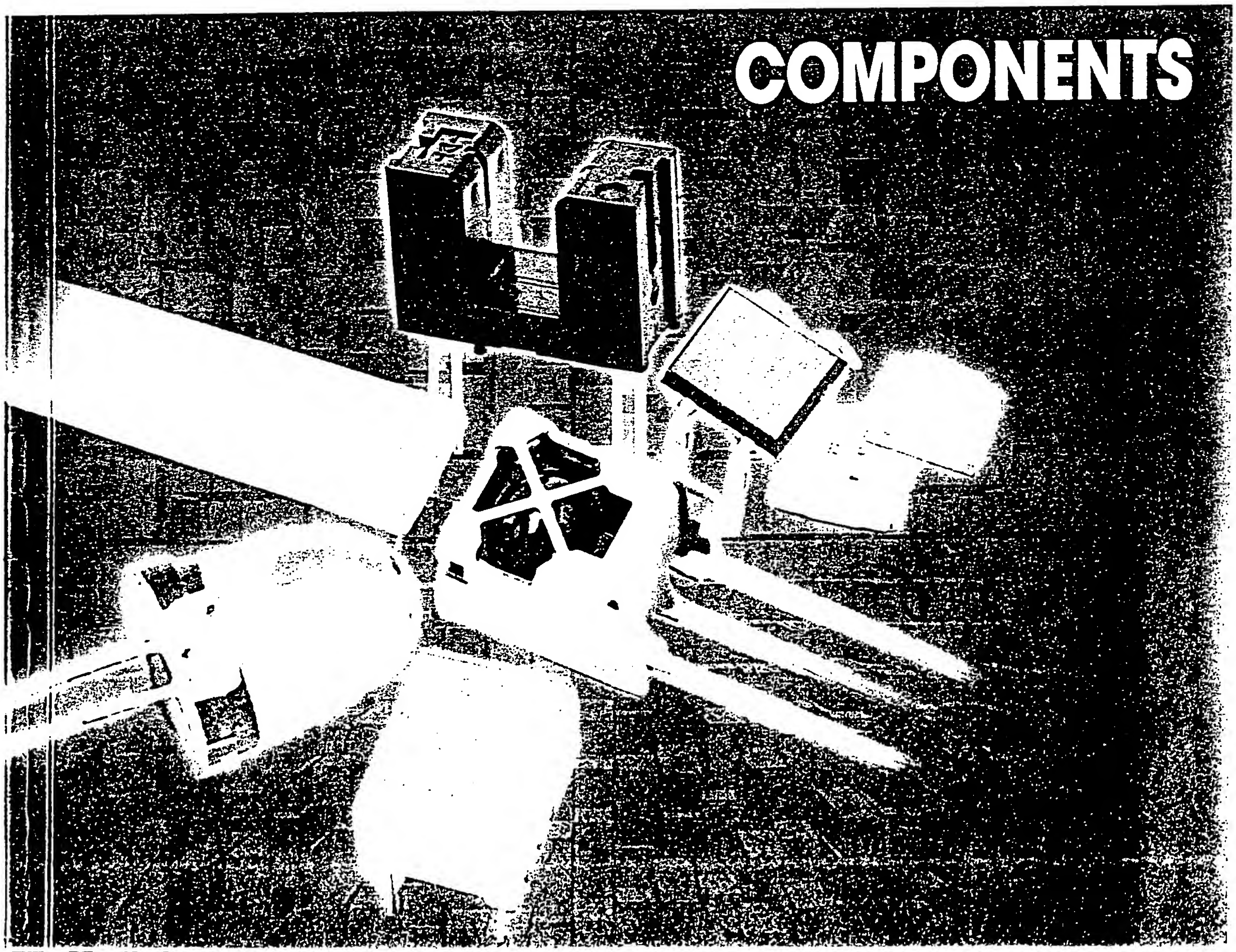
1999 B
SHORT FORM

EVERLIGHT

OPTO-ELECTRONIC
COMPONENTS

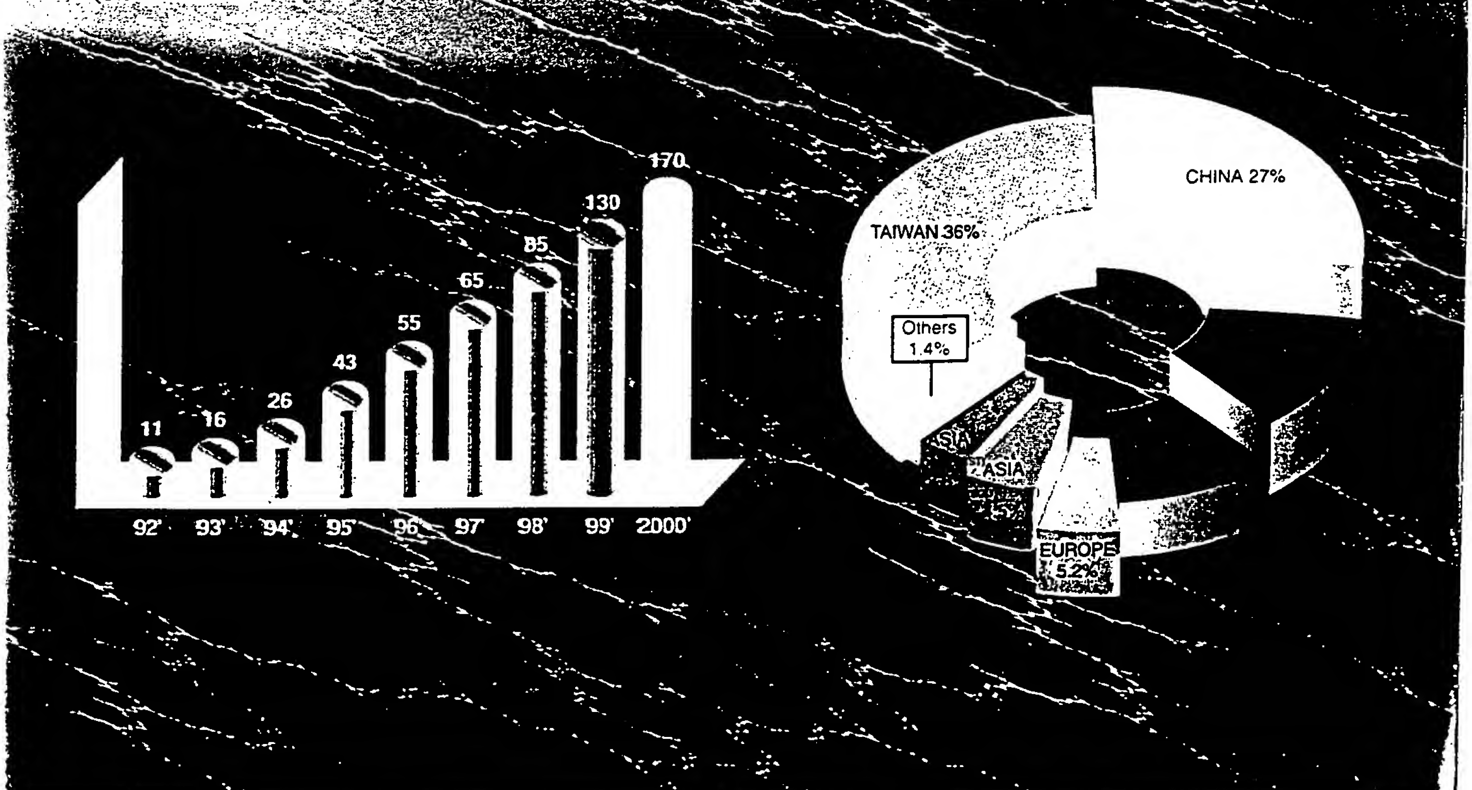


History in Brief

- **1983**
  Company established to produce LED Lamps.
- **1984**
  Started to produce invisible products (PT/IR/PD)
- **1989**
  Yue-Lee. Miao-Li Factory was built up
- **1990**
  Selected by SHARP. Japan as the only OEM collaborator in Taiwan
- **1991**
  Pan Yu Factory in Mainland China established
- **1991**
  Moved to new a building in Tucheng (floor size:11.570m²)
- **1993**
  Successfully developed Light Source. IRM and Big Lamp
- **1994**
  Selected by Quality Technologies(QT) as the OEM collaborator in Taiwan
- **1995**
  ISO-9002 certification
- **1996**
  ISO-9001 certification
- **1996**
  Successfully developed complete SMD series and became a main supplier of diversified mini LED of the world
- **1997**
  Successfully developed LASER Diode. mini IRM. PSD. IrDA and Hall IC
- **1997**
  Applied QS-9000. ISO-14000 to enter into automobile and aviation parts market
- **1998**
  Company traded in OTC market
- **1998**
  Successfully developed WHITE Lamps & relative products
- **1998**
  QS-9000 certification
- **1998**
  To purchase land (23.140m²) in Lung Tang. Taiwan for factory expansion
- **1998**
  To Purchase land(120.000m²)in Guangzhou for factory expansion
- **1998**
  Applied for public listing company in TAIEX
- **2000**
  Estimated to attain an annual sales of 5.5 billion NT dollars

Sales Billing

(U.S. million dollars)

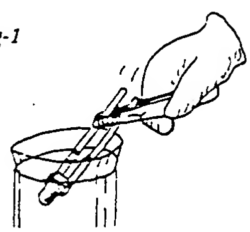


Generally, the LED can be used the same way as other general purposed semiconductors. However, the following precautions must be taken to protect the LED

▶ CLEANING

Don't used unspecified chemical liquids to clean the LED, they could harm the resin of the LED, If cleaning is necessary, please immerse the LED in alcohol or Freon TE at normal temperature for less than one minute. When other chemical solutions not specified are used, it may cause cracks or haze on the surfaces of the lens.(Fig-1)

Fig-1



▶ FORMING

1. Don't form the leads during or after soldering. If forming is required, it must be done before soldering.
2. Please remember, any pressure applied on resin can break gold wire in LED.
3. Form pin leads by securing under the tie bar cut(Fig-2-1), and bending with radio pliers, or the equivalent to avoid pressure on resin.(Fig-2-2)

Fig-2-1

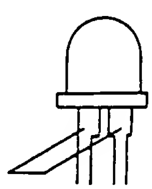


Fig-2-2

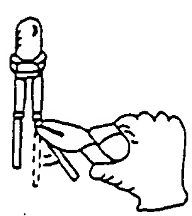
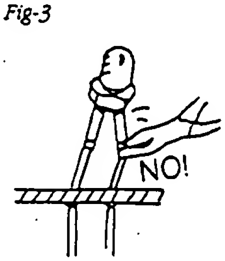


Fig-3



▶ SOLDERING

1. Solder under the tie bar cut(Fig-4). Hold pin leads with tweezers during solding, especially for smaller LEDs.

Fig-4

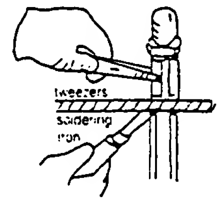
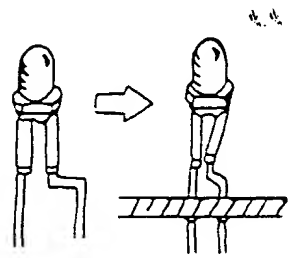
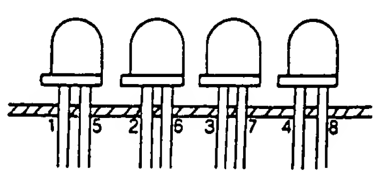


Fig-5

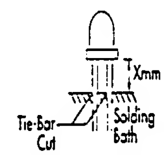
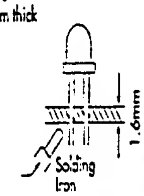


2. If pressure is a applied on LED while it is being on P.C. board, disconnection may occur during soldering or after mounting due to creep.Pin lead mounting holes must be coincided with original or formed pin lead pitch to prevent pressures.
3. During lead forming process should not be added any stress to the LED, otherwise fractures will be happended, The device epoxy and possibly break bond wires, which will cause failure.
4. When an LED is mounted into a P.C. board, pitch spacing should be aligned carefully to avoid causing any stress to the lead wires.Otherwise the stress will cause problem in high temperatur operation. It is necessary for the LED to return to normal temperature in three minutes after the soldering operation.(Fig-5)
5. If soldering one line of LEDs on a P.C. board by using a soldering iron, dont solder both leads of theLED at the same time.(Fig-6)

Fig-6



6. The soldering iron should be operated under 30W power consumption.
7. The LED soldering specification is shown as below:

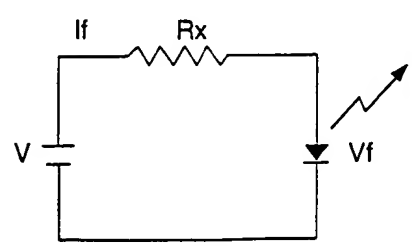
Method	Conditions	Temp.	Time
Soldering bath method	Dip LED up to Xmm from Resin 	230°C±5	Within 3 Seconds
Soldering method	Soldering iron: 30W Tip: 4.5ø x 32mm Through hole P.C.B. 1.6mm thick 	Tip Temp. 295°C±5°C	Within 3 Seconds

▶ PREBENTING OVERCURRENT.

1. Do not overcurrent.
2. In order to operate the LED under stable conditions, put protective resistors in series.Resistor Values can be detemined by supply voltage or current for the LED. Recommended current for use is in the range of If 10mA.(Fig-7)
3. Circuit must be designed so that overvoltage (overcurrent)is not applied to the LED during ON/OFF switching.Transients or pulse current can damage the junction of the LED die.

▶ BRIGHTNESS AND COLOR

1. For obtaining more brightness, multiple LEDs should be kept at the same current.
2. Increase current to increase brightness.
3. Check defects at a distance of 30cm from the LED to the eye.
4. Use on If 20mA If possible to obtain the most uniform brightness on yellow and green LEDs.



$$If = \frac{V-Vf}{Rx}$$

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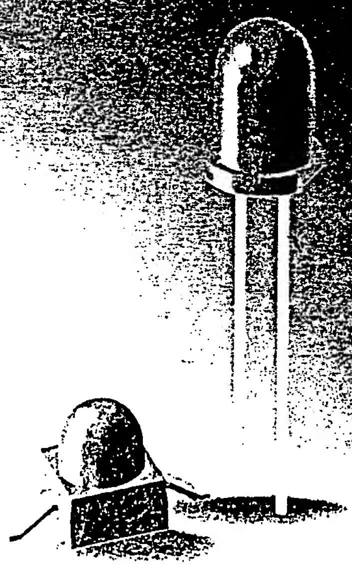

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BRIEF INTRODUCTION

J&K®

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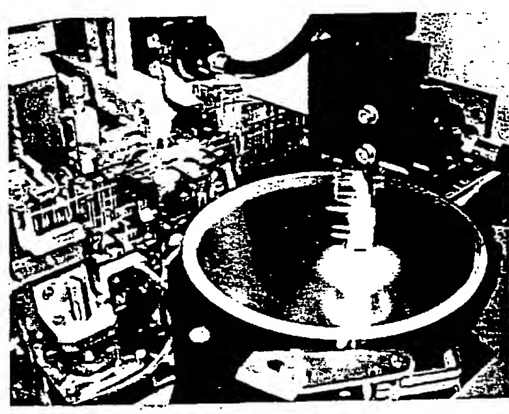
Super Bright Industrial Limited was established in 1986. We have two factories in Mainland China which are located in Guangdong has obtained ISO9002 Certification. Totaling 3000 sq. meter and employing about 1000 workers. Our monthly output is about 50 million pieces and is increasing steadily. We provide a wide range of products such as :

- LED Lamps
- Super Bright / Ultra Bright LED
- Axial LED, SMD
- Cluster LED
- Infra Red Emitters
- Photo Diodes, Photo Transistor
- Photo Interrupter
- Digit Display, Dot Natrix & Backlight.
- We also provide OEM & assembly aimed at custom design.

In order to improve the quality and reliability of our products, our R & D Division keep researching for new technologies and materials, such that Led Chips and other major materials are mainly imported from Taiwan & USA. Besides, we are using Automatic Die Bonder to facilitate production. To satisfy user's needs for high quality products, all of our products are checked by Fully Auto Test & Classification Machine. Molding parts are produced in house by modern machinery and facility. Thus, the fully control of manufacturing process is achieved.



Our company's common objectives towards our valuable customers are:

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- To provide high quality of products.
- To provide efficiency delivery.
- To strengthen the role of the cost control function in order to make our products becomes more competitive.

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Tel: (852) 2771 1665 Fax: (852) 2783 9543

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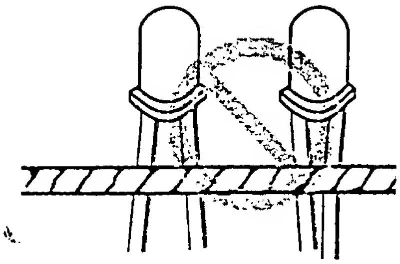
❑ CLEANING

Don't use unspecified chemical liquid because it may cause cracks or haze on the surface of lens. "Use Alcohol,Freon TE or Chlorosen to clean LED" at room temperature for less than 1 minute.

❑ FORMING

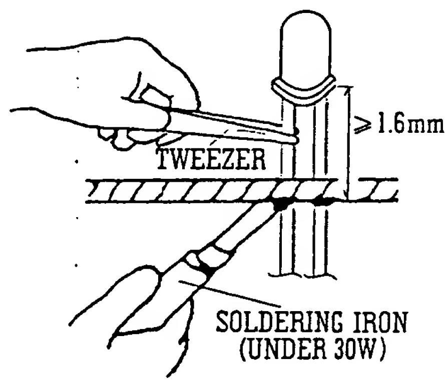


"If forming is required,it must be done before soldering."Form pin leads by securing under 5mm from body and bedding with radio pliers or the equivalent to avoid pressure on resin. "When the LED is mounted into a P.C.board,pitch" spacing should be aligned to prevent cause any stress to the resin.

Any unsuitable stress applied to resin may break "bonding wire in LED,which will cause failure."

❑ SOLDERING

(AUTOMATIC SOLDERING)



a.) Check and keep record of all soldering equipment's temperature .
b.) Pre-heating : 100°C max. (Resin surface temperature) 60 sec. Max
b.) Each soldering point must not exceed 5 second with 260°C
c.) Prevent any shock or vibration excise on the PCB shortly after soldering otherwise the bonding wire inside the led will be broken

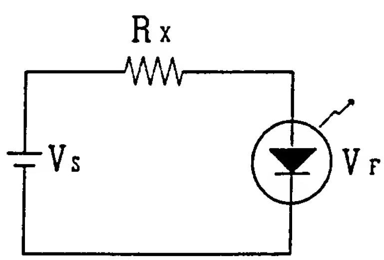
(HAND SOLDERING)

a.) It is suggested that using a fixture for soldering is needed during hand soldering to prevent heat transfer to the dice.
b.) Temperature at tip of iron: 300°C max. (30 W max.) soldering time:3 sec.max. Location: At least 3mm away from resin body
c.) Making sure of pitch of PCB and LED leads are the same, otherwise there might have strength transfer during insertion and causing damage to the gold wire when soldering.

❑ PREVENTING OVERCURRENT

Apply overcurrent may cause LED failure or reduce life and brightness. "Put protective resistor in series,not only prevent" "overcurrent,but also keep LED in uniform" brightness. Resistor value can be determined by the formula.

$$R_X = \frac{V_S - V_F}{I_F}$$



❑ BRIGHTNESS

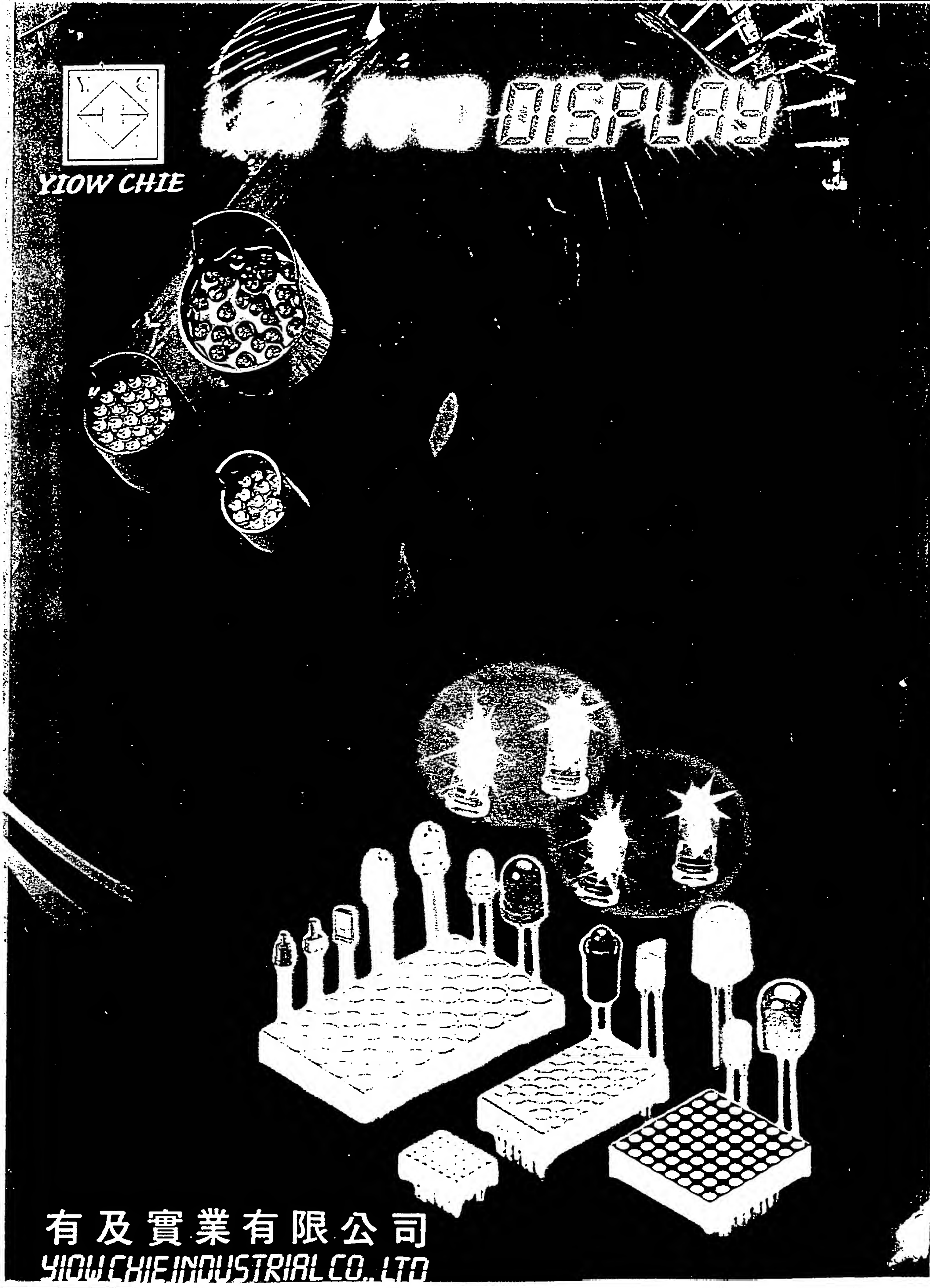
"For the purpose of obtaining uniform brightness," LED shall be Kept at the same current but not voltage.

It is useful for uniform bright if use larger source voltage and protective resistor.

Use on forward current 20mA to obtain the most uniform brightness on yellow and green LEDs.

NOTE: CHECK AT A DISTANCE OF 30cm FROM THE LED TO THE EYE DEFECTS.

D



HOW TO USE THE LED

Generally, the LED can be used the same way as other general purpose semiconductors. However, the following precautions must be taken to protect the LED.

■ CLEANING

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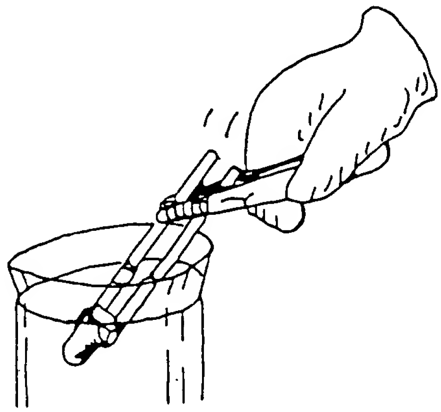
Fig-1



■ FORMING

1. Don't form during or after soldering. If forming is required it must be done before soldering.
2. Please remember, any pressure applied on resin can break gold wire in LED.
3. Form Pin by Leads securing under the tie bar cut (Fig. 2), and beddig with radio pliers or the equivalent to avoid pressure on resin. (Fig. 2)

Fig-2

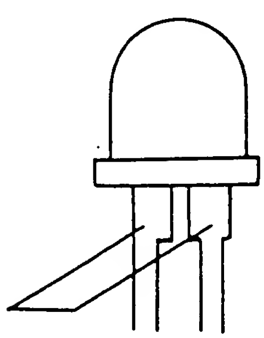


Fig-2

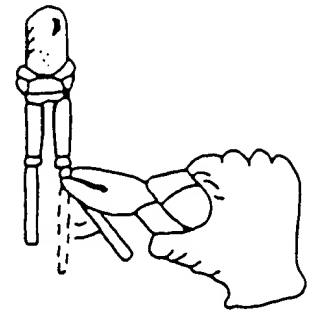
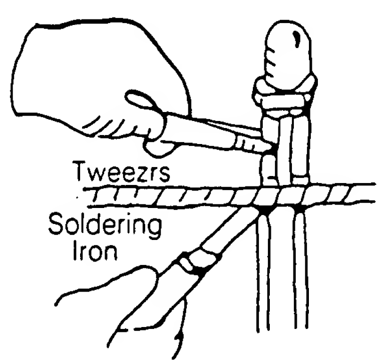


Fig-3

■ SOLDERING

1. Solder under the tie bar cut (Fig. 4). Hold pin Leads with tweezers during soldering, especially for smaller LEDs.

Fig-4



COMPANY PROFILE

YIOW CHIE INDUSTRIAL CO., LTD.

YIOW CHIE industrial co., ltd. was established in 1986, a specialist manufacturer of light emitted diode such as Led Lamps, Seven Segment Displays, Dot matrix, LED Light Bar and SMD.
Since the establishment of YIOW CHIE INDUSTRIAL CO., LTD. 15 years ago, under integrated efforts of our knowledgeable and experienced staff and managers. We have continued to develop the most advanced reliable products for our clients, hence we have contributed eminently to the electronic assembling industry.
For the past years with our customers patronage and support, YIOW CHIE has gained tremendous growth, and we are proud of our continuous offer of quality products to leading domestic and foreign electronic firms.
As we approach the year 2000, the electronics industry has progressed dramatically through the rapid development of new material technology. And in response to the evolving needs of the ear, we strive for complete office and engineering automation through the introduction of modern equipments and most recent R&D.
With dedication, YIOW CHIE pursuits for a progressive high-tech environment which serves man and society in an exciting and unprecedented way.
With all efforts, we will commit ourselves to our domestic and international clients. We thank you for your continuous support and guidance and your patronage is always welcomed.

The yield of leds lamp is 20KK pcs and 500kpcs for led display monthly.

Please contact us through:

OFFICE: Yiow Chie Industrial Co., Ltd.
10Fl, No. 120-11, Sec. 3, Chung-San Rd., Chung Ho City, Taipei, Taiwan, R.O.C.
TEL : 886-2-2221-3358
FAX : 886-2-2221-3821
E-MAIL : yiowchie@ms19.hinet.net
yiowchie@yiowchie.com.tw
WEBSITE : http://www.yiowchie.com.tw/

HONG KONG OFFICE: Skytruth International Co., Ltd.
Rm., 4, 10/F, Yale Industrial Centre, 61-63, Au Pui Wan Street, Fo Tan, Shatin, N.T.
Hong Kong
TEL: 852 2605 7432
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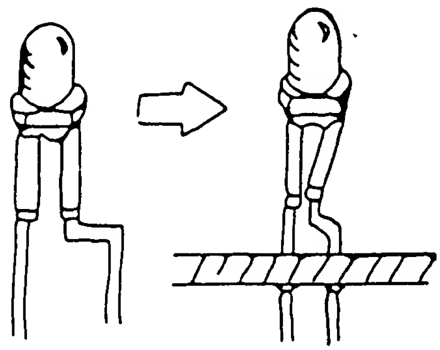
FACTORY: Shanghai Jialong Electronicc Co., Ltd.
No. 511, Jialow Highway, Jiading, Shanghai
TEL: 86 21 5954 9613 . 5954 9654
FAX: 86 21 5954 9288

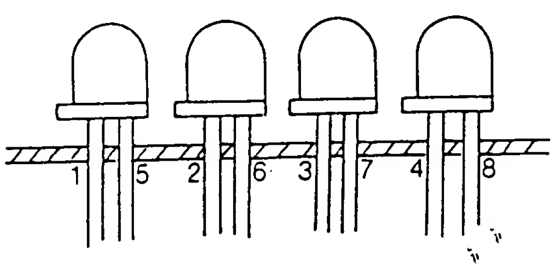
Fig-5



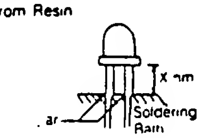
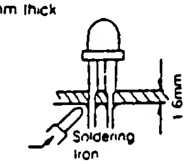
2. If pressure is applied on LED while it is being on P.C. board, disconnection may occure during soldaring or after mounting due to creep.Pin Lead mounting holes must be coincided with original or formed pin Lead pitch to prevent pressures.
3. During Lead forming process should not be added any stress to the LED , otherwise fractures will be happened. The device epoxy and possibly break bond wires, which will cause failure.
4. When an LED is mounted into a P.C. board, pitch spacing should be aligned carefully to prevent cause any stress to the Lead wires. Otherwise the stress will cause problems in high temperature operation. Three minutes are necessary for the LED to return to normal temperature after the soldering operation. (Fig. 5)
5. If soldering one line of LEDs on a P.C. board by using a soldering iron, don't solder both the Leads of the LED at the same time. (Fig. 6)

Fig-6

weezers



6. The soldering iron should be operated at under 30W power consumption.
7. The LED soldering specification is shown as below:

Method	Conditions	Temp	Time
Soldering bath method	Dip LED up to Xmm from Resin 	230°C ± 5	Within 3 Seconds
Soldering method	Soldering iron 30W Tip 4.5φ × 32mm Through hole P.C.B 1.6mm thick 	Tip Temp 295°C ± 5°C	Within 3 Seconds

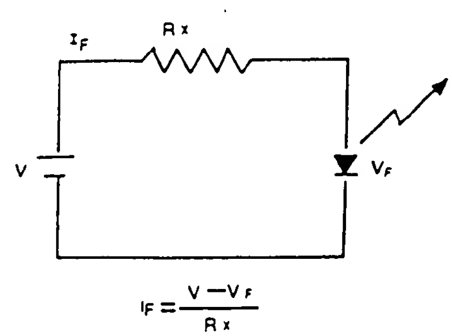
■ PREVENTING OVERCURRENT.

1. Do not overcurrent.
2. In order to operate the LED under stable conditions. Put protective resistors in series. Resistor Values can be determined by supply Voltage or current for the LED. Recommended current for use is in the range of I_F 10mA to 20mA. (Fig. 7)
3. Circuit must be designed so that overvoltage (overcurrent) is not applied to the LED during ON/OFF switching. Transients or pulse current can damage the junction of the LED die.

■ BRIGHTNESS AND COLOR

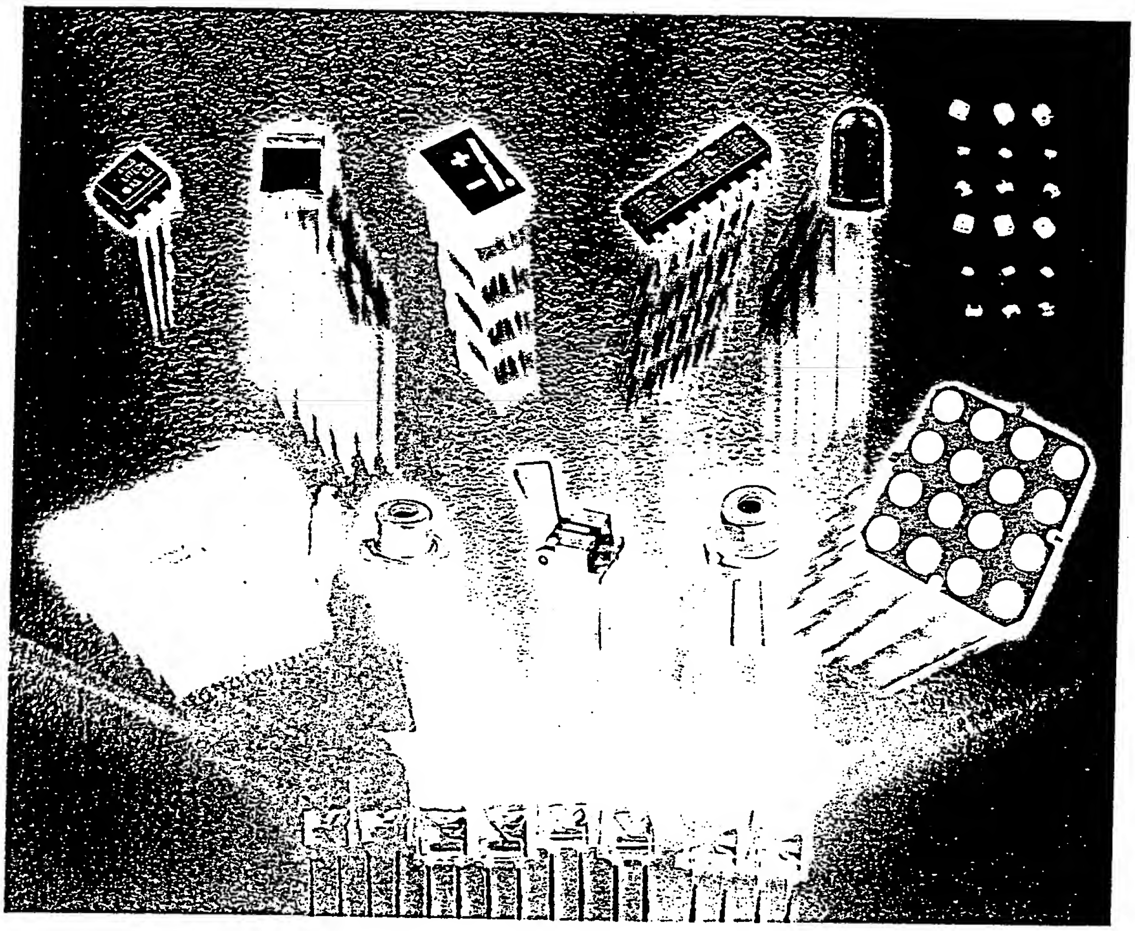
1. For obtaining even brightness multiple LEDs should be kept at the same current.
2. Increase current to increase brightness.
3. Check at a distance of 30cm from the LED to the eye defects.
4. Use on I_F 20mA if possible to obtain the most uniform brightness on yellow and green LEDs.

Fig-7



$$I_F = \frac{V - V_F}{R_x}$$

t



Optoelectronics

SHORT FORM
1998 – 1999

As one of the world's largest independent manufactures of optoelectronic products, LITE-ON offers a wide range of reliable and economical optoelectronic design solutions.LITE-ON is the first IECQ - certified opto products manufacturer in the world , also qualified for ISO 9000 & ISO 14000 certification.

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Our fully automated production facilities in Taiwan , Thailand and Tianjin also features the very latest in production equipment - much of which was designed by LITE-ON engineers - and provides the most comprehensive reliability test facilities in the industry.

The LITE-ON product line is backed by a team of experienced support specialists. So you can be assured that your problems and questions will be met with professionalism and expediency.

To order any component in this SHORT FORM or additional applications information, call the LITE-ON office nearest you. Please refer to address list.

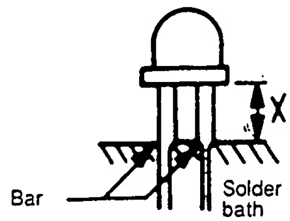
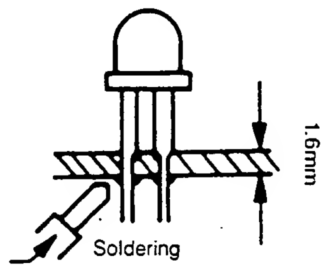
We reserve the right to amend any specifications / information without prior notice.

Editor

LITE-ON ELECTRONICS, INC.
Address: 90, Chien I Road, Chung Ho, Taipei Hsien, Taiwan, R.O.C.
TEL : +886-2-22226181
FAX : +886-2-22210660 / 22256846

How To Use LITE-ON LED Lamps

3.6 The soldering iron should be operated at under 30w power consumption.
3.7 The LITE-ON LED soldering specification is shown as below:

Method	Conditions	Temp	Time
Soldering bath method	Dip LED up to Xmm from resin 	230 ℃± 5	Within 5 Seconds
Soldering method	Soldering iron: 30W Tip: 4.5 ϕ x32mm Through hole P.C.B. 1.6mm thick 	Tip Temp 295 ℃± 5 ℃	Within 3 Seconds

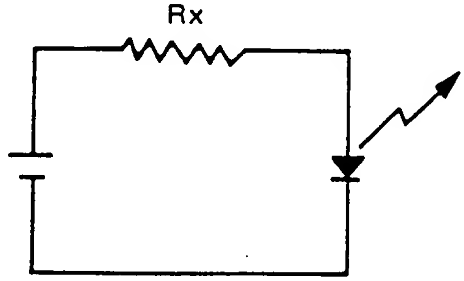
4. Preventing Overcurrent

4.1 Do not overcurrent.
4.2 In order to operate LITE-ON LED under stable conditions, put protective resistors in series, Resistor Values can be determined by supply voltage or current for the LED. Recommended current for use is in the range of IF 10mA to 20mA. (fig.7)
4.3 Circuit must be designed so that overvoltage (overcurrent) is not applied to the LED during ON/OFF switching. Transients or pulse current can damage the junction of the LED die.

5. Brightness and Color

5.1 For obtain even brightness multiple LED should be kept at the same current.
5.2 To increase brightness, increase current.
5.3 It checked at a distance of 30cm from the LED to the eye detects.

FIG. 7



F

Duane J. Knize
5572 Ladybird Ln
La Jolla, California 92037
September 28, 2000

Mark Allen
Fiber Optics Designs
Research and Development Office
7601 Eads Avenue, Suite 8
La Jolla, California 92037

Dear Mr. Allen,

I was asked to comment on patent 5,941,626 regarding the requirement for, and use of, a resistor in the LED circuits described in the patent and to disclose my qualifications to make these comments.

Background Information: I received Bachelor of Science and Master of Science degrees in electrical engineering from Harvey Mudd College, Claremont California, in 1973. I have over 27 years of engineering experience including circuit and electronic system design and development. I am currently Chief Scientist for the Technology Research Group at Science Applications International Corporation. SAIC is a large engineering service firm with revenues over $4B/year, supporting government and commercial clients. TRG is, as the name implies, the premier technology R&D organization in the company.

Comments on Patent 5,941,626: First of all, all the art showing circuit detail includes a resistor. Specifically, figure 1A, showing the circuit configuration, and figure 1B, showing the circuit schematic of the first embodiment of the invention include a resistor. No detailed configuration or schematic is provided for the second embodiment. Although it is mechanically different, it uses a circuit identical to that of the first embodiment (as explicitly stated in column 6, lines 34-36). Figures 10A and 10B provide the circuit configuration the circuit schematic of the third embodiment of the invention. Both include a resistor.

Secondly, the discussion contained in column 3 lines 30-40 clearly promulgates a requirement for this resistor. The wording stresses the fact that one might not think that a resistor is required ("Since the required power source of 100V is equal to the current (sic) source voltage in Japan, the resistance 8 apparently seems unnecessary."), but in fact it is ("However, it is proved from experience that the apparatus is stable in function by providing the resistance 8.").

Finally, nowhere in the patent is any reference or allusion to a version of the apparatus operating without a stabilizing resistor.

It seems clear to me that the author of patent 5,941,626 considered the resistor to be an essential part of his invention.

If you have any questions, please don't hesitate to call me during business hours at 858-826-6544.

Best regards,

Duane J. Knize

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Pulsed Operating Ranges for AlInGaP LEDs vs. Projected Long Term Light Output Performance

Application Brief I-024

Introduction

There have been two significant questions related to pulsing AlInGaP LEDs in various applications. The first question is what is a safe maximum peak current and duty factor for AlInGaP LEDs? The second question is what long term performance can be projected for AlInGaP LEDs operated at various pulsed drive conditions?

This application brief presents data and accompanying discussion that addresses both of these questions.

The Need for Pulsed Drive Conditions

LEDs need to be strobed at some pulsed drive condition whenever high light output for a short duration is necessary, or when displaying variable and changing characters or images across the face of a matrix display. The selection of the pulse condition is usually based on the time average luminous intensity required for the application.

Primary considerations used to set pulsed drive conditions for LEDs include:

- Luminous intensity at the peak current, I_V PEAK (mcd)
- Peak current, I_{PEAK} (mA)
- On-time duty factor, DF (%)
- Maximum allowed LED device junction temperature, T_J MAX (°C)
- Strobing rate, f (Hz)

For a simple square wave, the I_{PEAK} x DF determines the time average current, I_{AVG} (mA). The achieved time average luminous intensity is the light output at the peak current, I_V PEAK (mcd) x DF.

The strobing rate (pulse rate), f (Hz), should be faster than 100 Hz to minimize observable flicker. The optimum strobing rate is 1000 Hz.

To summarize here, it is the necessary time average luminous intensity for a determined on-time duty factor that leads to selection of peak drive current.

Maximum Peak Current

Maximum peak current for an LED technology is based on the current density, in amperes per square centimeter, J (A/cm^2), the LED chips can withstand without damage, and the measured rate of light output degradation at that peak current. Light output degradation for AlInGaP LEDs is primarily a function of current density at the peak current over a collective period of on-time. It is not a function of I_{AVG}.

Basic Theory

The following theory lays the ground work for understanding the discussion on driving AlInGaP LEDs at various pulsed drive conditions. It is assumed that a rectangular current pulse train is used to drive the LEDs. Driving LEDs by rectified ac current gives a different result.

Light output degradation vs. on-time. Light output degradation of LEDs only occurs when forward current is flowing through the LED *p-n* junction. At any selected forward current, some amount of light output degradation will occur during the current pulse on-time period. The amount of light output degradation over an elapsed time period is the accumulated degradation of the collective on-time periods within an elapsed time period.

An example: A hypothetical example is shown in Figure 1. An LED driven at a 10% on-time duty factor will experience light output

degradation for 10 on-time hours out of every 100 hours of elapsed time. If the light output degradation rate at the selected peak forward current is hypothetically -5% per decade on-time hours, then:

- After 100 hours of elapsed time, the LEDs will have degraded by approximately -5%,
- -10% after 1,000 hours elapsed time,
- -15% after 10,000 hours of elapsed time, and
- -20% after 100,000 hours of elapsed time.

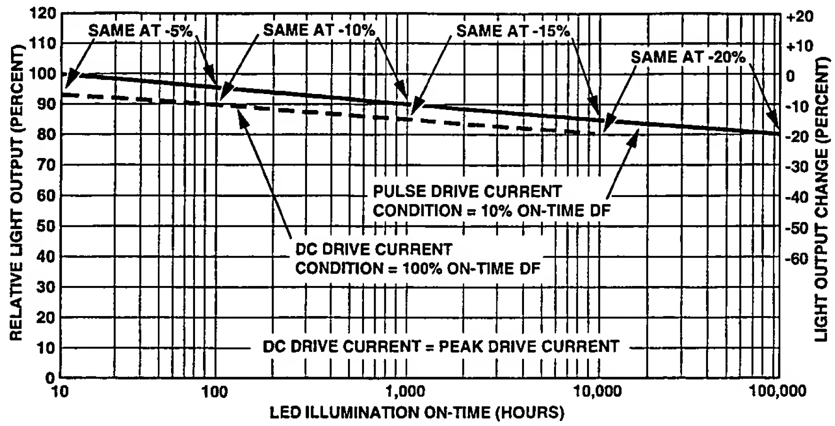

Figure 1. Comparison of Hypothetical LED Degradation of -5% per Decade On-Time Hours for 10% DF Pulsed Drive Condition vs. dc Drive Condition (100% DF), where dc Current Value = Peak Pulse Current Value.

This same LED driven under dc conditions, 100% on-time duty factor, at the same selected forward current, will experience light output degradation on an LED on-time basis (LED on-time = elapsed time).

- After 10 hours of LED on-time the light output degradation will be about -5% (equivalent to the above 100 elapsed time hours of 10% DF on-time pulsing),
- -10% after 100 hours (equivalent to the above 1,000 elapsed time hours of 10% DF on-time pulsing),
- -15% after 1,000 hours (equivalent to the above 10,000 elapsed time hours of 10% DF on-time pulsing), and
- -20% after 10,000 hours (equivalent to the above 100,000 elapsed time hours of 10% DF on-time pulsing).

Table 1. DC and Pulsed Drive Current Conditions Used for HTOL Testing

dc Drive Conditions	10%DF Conditions	I_{AVG} = 30 mA Conditions
20 mA dc	I_{PEAK} = 30 mA	I_{PEAK} = 50 mA, DF = 60%
30 mA dc	I_{PEAK} = 50 mA	I_{PEAK} = 75 mA, DF = 40%
50 mA dc	I_{PEAK} = 75 mA	I_{PEAK} = 100 mA, DF = 30%
	I_{PEAK} = 100 mA	

Table 2. Absolute Maximum Drive Currents

I_{DC} MAX	I_{PEAK} MAX	I_{AVG} MAX
50 mA	100 mA	30 mA

Pulsed Drive Conditions for AlInGaP LEDs

Long term high temperature operating life (HTOL) data at 55°C have been evaluated by Hewlett-Packard to determine the range of recommended pulsed and dc current operating conditions for AlInGaP LEDs. The drive current conditions used in these HTOL tests are listed in Table 1.

Using the results from the above HTOL testing, the absolute maximum drive current conditions, listed in Table 2, have been established for T-1³/₄ AlInGaP LED lamps.

Designers should adhere to these maximum drive current conditions for both rectangular drive current pulses and rectified ac drive current.

The range for the recommended pulsed and dc drive current conditions for AlInGaP T-1³/₄ LED lamps is shown in Figure 2. The boundary is from 100 mA peak and 30% DF to 50 mA dc. Operation anywhere within this range ensures operation without overdriving the LEDs.

Operation within the recommended range, shown in Figure 2, does not necessarily ensure a light output degradation that is acceptable in all kinds of applications. The long term light output degradation for a selected pulse drive

current condition must be evaluated to determine the acceptability for a given application.

AlInGaP T-1$^{3}/_{4}$ LED lamps may be operated at peak drive currents less than 10 mA. However, attention to special considerations is required to ensure reliable operation. Designers are encouraged to contact Hewlett-Packard before proceeding with a design that utilizes an LED drive current less than 10 mA.

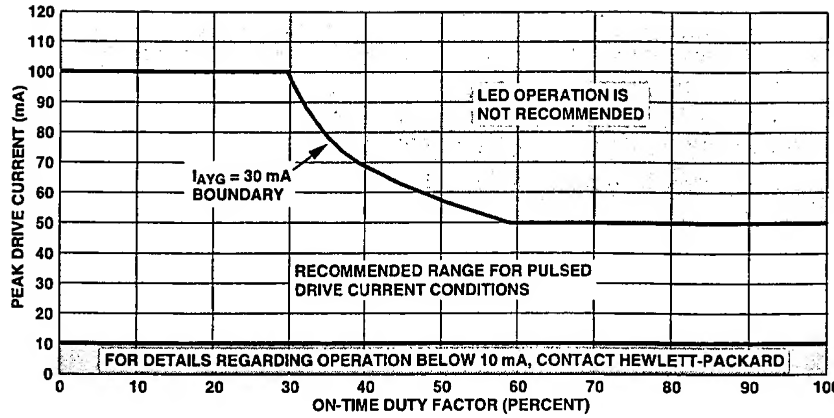

Figure 2. Recommended Range for Pulsed Drive Current Conditions for AlInGaP LEDs

Projected Long Term Performance for Various Drive Current Conditions

The projected light output degradation for each of the above listed drive current conditions is graphed as straight lines on semi-log plots for comparison purposes. These degradation graphs are projected typical performance, based on +55°C high temperature operating life (HTOL) test data out to 12,000 hours. For this reason, these graphs are only projections and the actual long term performance out to 100,000 hours cannot be guaranteed by Hewlett-Packard.

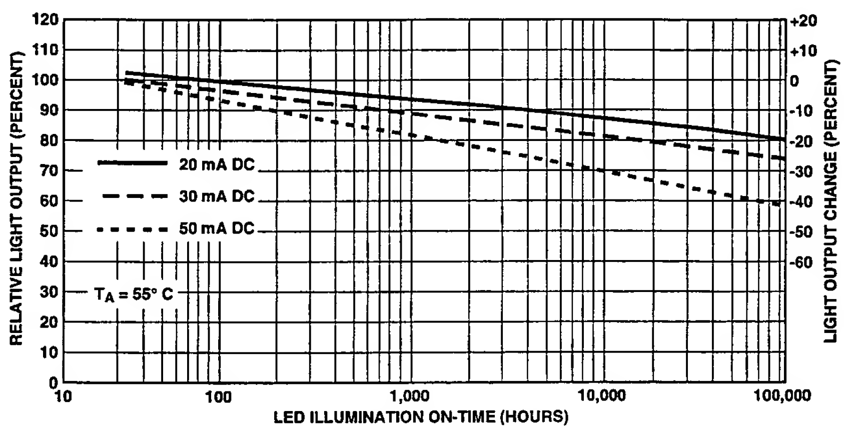

Figure 3. Projected Long Term Light Output Degradation for dc Drive Currents

Dc drive conditions. Figure 3 contains curves that project the long term light output performance for 20 mA dc, 30 mA dc, and 50 mA dc drive currents. DC drive currents between 20 mA and 30 mA exhibit long term degradation that is projected to be on average less than -30% after 100,000 hours of LED on-time.

Increasing the dc drive current above 30 mA results in additional degradation, as is exhibited by 50 mA dc. At 100,000 hours of LED on-time, the light output degradation for 50 mA dc is projected to be on average greater than -40%.

Pulsed operating conditions with 10% LED on-time duty factor. Figure 4 contains curves that project the long term light output performance for pulsed drive conditions where the LED on-time duty factor is 10%. At 100,000 hours of elapsed time, the cumulative LED on-time is 10,000 hours. For peak drive currents up to 50 mA, the long term degradation is projected to be on average about -30% after 100,000 hours of elapsed time. The light output degradation in Figure 4 for 30 mA and 50 mA peak currents at 10% DF, after 100,000 hours of elapsed time, can be compared to the degradation shown in Figure 3 for 30 mA dc and 50 mA dc, respectively, after 10,000 hours of LED on-time. At these respective time points, the light output degradations are approximately the same.

Increasing the peak drive current above 50 mA results in a considerable increase in degradation. At 100,000 hours of elapsed time, the light output degradation for a peak current of 75 mA dc is projected to be on average near -40%, and with the peak drive current increased to 100 mA the degradation is projected to increase to an average near -50%.

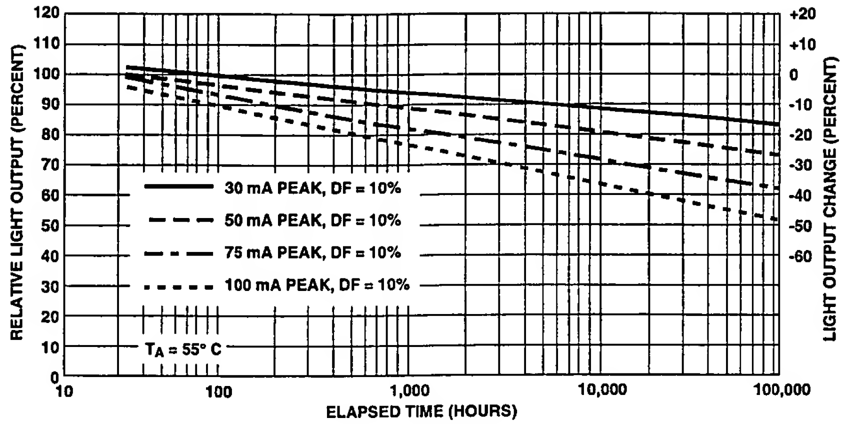

Figure 4. Projected Long Term Light Output Degradation for Pulsed Drive Conditions with an LED On-Time Duty Factor of 10%

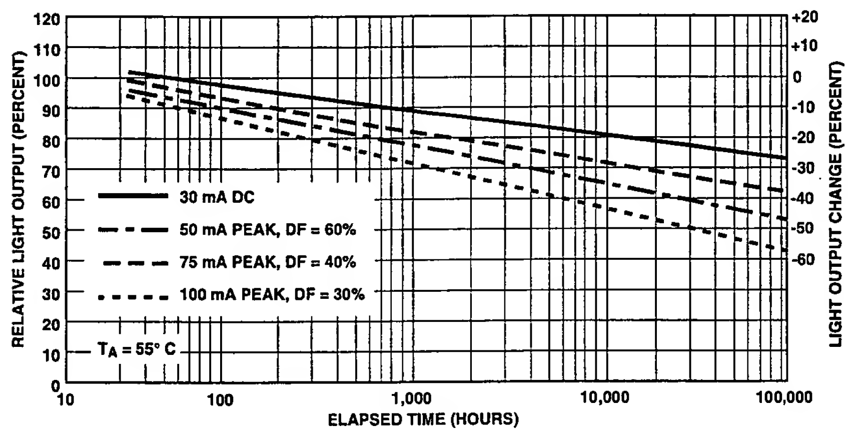

Figure 5. Projected Long Term Light Output Degradation for Pulsed Drive Conditions with the LED On-Time Duty Adjusted to Provide an I_{AVG} = 30 mA

Pulsed operating conditions with DF adjusted to provide I_{AVG} = 30 mA.
Figure 5 presents curves that project the long term light output performance for pulsed drive conditions where the DF is adjusted to provide a time average current of 30 mA. The curve of degradation for 30 mA dc drive current is included to provide a direct visual comparison with the pulsed drive conditions.

For a peak drive current of 50 mA, the DF is set at 60% and the cumulative LED on-time is 60,000 hours at 100,000 hours of elapsed time. The typical long term degradation is projected to be near -40% after 100,000 hours of elapsed time.

If a DF is set at 40% for the peak current of 75 mA, the long term degradation is projected to be typically about -47% after 100,000 hours of elapsed time.

If a DF of 30% is set for a peak drive current of 100 mA, the long term degradation is projected to be considerable, typically -58% after 100,000 hours of elapsed time.

The light output degradations in Figure 5 for the pulsed operating conditions can be compared to the 30 mA dc degradation curve. For all three pulse conditions, the light output degradation is greater than that for 30 mA dc.

The Hewlett-Packard AlInGaP LED Extended Warranty

Hewlett-Packard provides an Extended Warranty for AlInGaP T-1 3/4 plastic LED lamps that ensures sufficient light output for a period of 5 years, where sufficient light output is defined as less than -50% on average light output degradation during the 5 year period. The following drive current limits are defined within the text of the Extended Warranty:

1. For dc operation, the LED drive currents are maintained between 10 mA dc and 30 mA dc.
2. For pulsed operation, the LED drive peak current must be above 10 mA and must not exceed 70 mA.
3. Average currents must not exceed 30 mA (i.e. DF MAX = 50% at 60 mA PEAK; DF MAX = 43% at 70 mA PEAK). At DF greater than 50%, I_{PEAK} must not exceed 30 mA.

Failure to comply with these drive current conditions, and warranty specified environmental conditions, voids the Extended Warranty.

Figure 6 shows the pulsed current operation range for the Hewlett-Packard AlInGaP LED Extended Warranty. The warranty pulsed current operating range is a subset of the larger recommended operating range shown in Figure 2. Pulsed current operation anywhere within this warranty drive current range ensures less than -50% on average light output degradation from AlInGaP T-1 3/4 LED lamps for a period of 5 years.

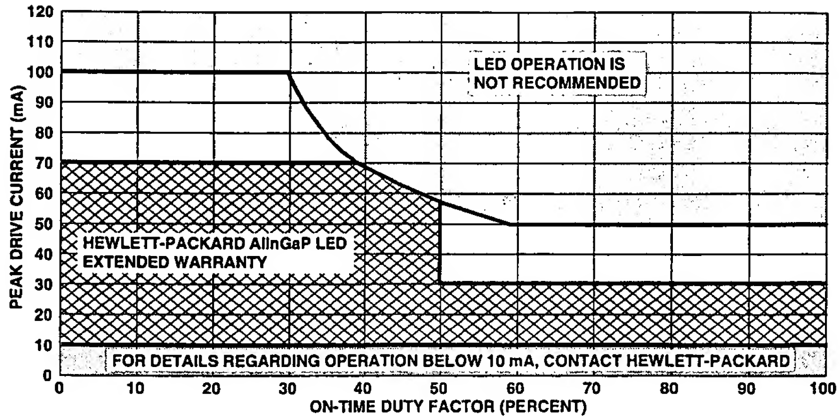

Figure 6. Hewlett-Packard AlInGaP LED Extended Warranty Pulsed Current Operating Range

The Suitability of Various LED Drive Current Conditions

It is important for designers to understand the suitability of various drive current conditions as they apply to different applications. The necessary minimum light output at the end of operational life for a product using AlInGaP LEDs may be set by regulation or may be based on human factors data. In either case, the LED drive current condition should be chosen to ensure the LED long term light output degradation is compatible with the light output requirements of the application.

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Some Suggested Maximum dc and Pulsed Current Operating Conditions

Table 3 offers suggested dc and pulsed drive current conditions for various applications. For purposes of this application brief, a long term average light output degradation of -40% is assumed for each application. This assumption, however, may not be an acceptable real world requirement for all applications. The actual drive condition selected for a particular application should be checked against the curves of Figures 3, 4, and 5 to ensure the projected long term average light output degradation of AlInGaP LEDs is in concert with the end product design and mission objectives.

Table 3. Suggested Maximum dc and Pulsed Drive Current Conditions for T-1¾ AlInGaP LED Lamps in Various Applications

Application	Suggested Maximum Drive Current Conditions	Projected Degradation Information
Traffic Signal Modules and Railroad Signal Modules	I_{DC} MAX = 30 mA I_{PEAK} MAX = 50 mA with 10% DF	Figure 3, 30 mA dc curve. Figure 4, 50 mA PEAK curve.
Over Roadway and Trailer Mounted Variable Message Signs (VMS).	I_{PEAK} MAX = 30 mA	Figure 4, 30 mA PEAK curve.
Barricade Lights: Type A Type B Type C	I_{DC} MAX = 30 mA I_{DC} MAX = 30 mA I_{PEAK} MAX = 75 mA at 65 Flashes/Minute	Figure 3, 30 mA dc curve. Figure 3, 30 mA dc curve. Figure 4, 75 mA PEAK curve.
Beacon Flasher	I_{PEAK} MAX = 75 mA at 65 Flashes/Minute	Figure 4, 75 mA PEAK curve.
EXIT Signs	I_{DC} MAX = 30 mA	Figure 3, 30 mA dc curve.
Emergency Signs	I_{PEAK} MAX = 100 mA with 30% DF	Figure 5, 100 mA PEAK curve.
Commercial Advertising Signs	I_{PEAK} MAX = 50 mA with 60% DF	Figure 5, 50 mA PEAK curve.

www.hp.com/go/led_lamps

For technical assistance or the location of your nearest Hewlett-Packard sales office, distributor or representative call:

Americas/Canada: 1-800-235-0312 or (408) 654-8675

Far East/Australasia: Call your local HP sales office.

Japan: (81 3) 3335-8152

Europe: Call your local HP sales office.

Data Subject to Change

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Operational Considerations for LED Lamps and Display Devices

Application Note 1005

In the design of a drive circuit for an LED lamp, an LED light bar, or an LED 7-segment display, the objective is to achieve optimum light output, power dissipation, reliability, and operating life. The performance capabilities of each LED device are presented in the device data sheet. The data sheet contains tabular data and graphs that describe the optical and electrical characteristics of the LED device, and Absolute Maximum Ratings which are the maximum operating capabilities of the device. A thorough understanding of how to use this information is the basis for achieving an optimum design.

This application note presents an in-depth discussion of the use of the optical and electrical information contained in an LED device data sheet. Design examples for dc and pulsed operation are presented. The calculated results for each example are in **Bold Type** for identification.

Typical Data Sheet Information

Data sheets typically contain three tables of data. Usually for LED lamp devices the first table is titled **Device Selection Guide** or **Axial Luminous Intensity and Viewing Angle at T_A = 25°C** and presents the basic optical characteristics of the devices listed in the data sheet. The luminous intensity, I_V, both minimum and typical values, are listed in this table. This table is used as a device selection guide.

The next table is titled **Absolute Maximum Ratings at T_A = 25°C**, containing maximum peak, dc and average currents, maximum transient current, operating and storage temperature range, and the absolute maximum LED junction temperature. These are the maximum allowed operating conditions for all the devices in the data sheet.

The third table, titled **Electrical/Optical Characteristics at T_A = 25°C**, contains the electrical data, and some optical data, that are used to determine the operating conditions for the device. The forward voltage, V_F, and device thermal resistance, $R\theta_{J\text{-}PIN}$, used in operating condition calculations, are listed in this table.

The graphs usually contained in a lamp data sheet used to determine operational conditions are:

Figure 1. Relative Intensity vs. Wavelength. (not shown here)

Figure 2. Forward Current vs. Forward Voltage.

Figure 3. Relative Luminous Intensity vs. DC Forward Current.

Figure 4. Relative Efficiency vs. Peak Current. (This figure is not included on all data sheets.)

Figure 5. Maximum Forward DC Current vs. Ambient Temperature.

Figure 6. Maximum Average Current vs. Peak Forward Current.

Figure 7. Relative Luminous Intensity vs. Angular Displacement. (not shown here)

Design Criteria

The two criteria that establish the operating limits are the maximum

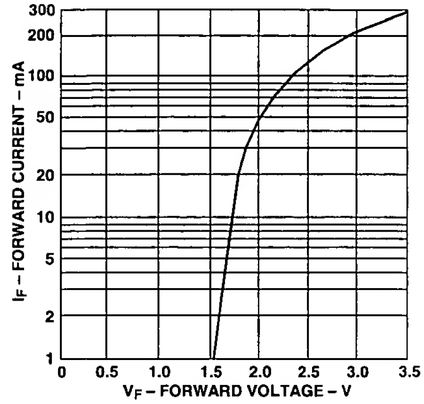

Figure 2. Forward Current vs. Forward Voltage.

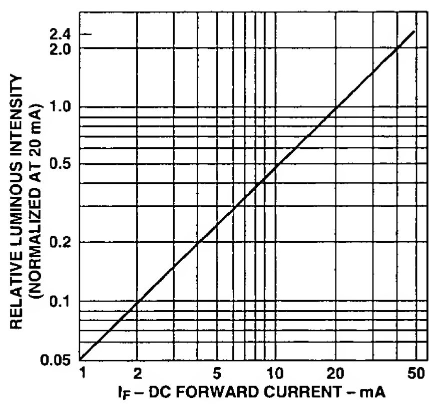

Figure 3. Relative Luminous Intensity vs. DC Forward Current.

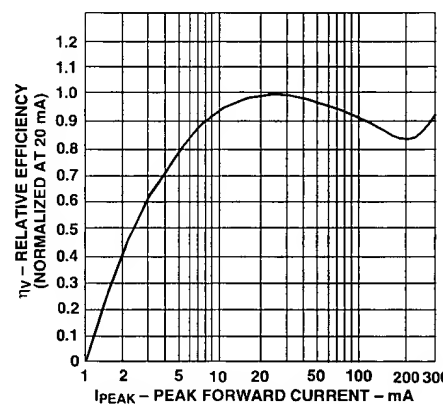

Figure 4. Relative Efficiency vs. Peak Forward Current.

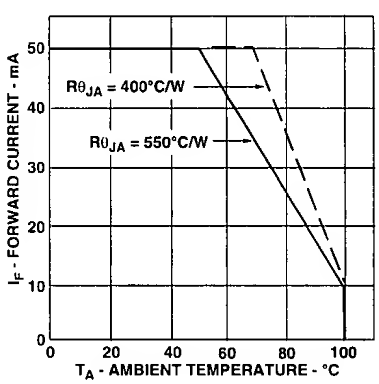

Figure 5. Maximum Forward DC Current vs. Ambient Temperature. Derating Based on T_JMAX = 110°C.

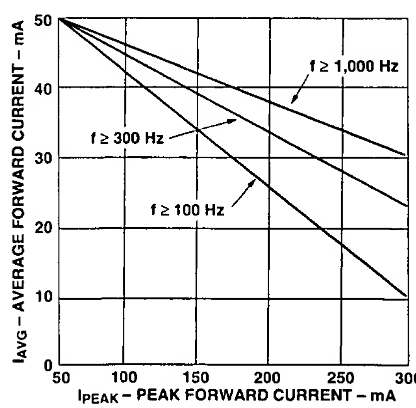

Figure 6. Maximum Average Current vs. Peak forward Current.

drive currents and the absolute maximum LED junction temperature, $T_J MAX$. The maximum drive currents have been established to ensure long operating life. The absolute maximum LED junction temperature is a device package limitation that must not be exceeded.

Thermal Resistance

The LED junction temperature, $T_J(°C)$, is the sum of the ambient temperature, $T_A(°C)$, and the temperature rise of the LED junction above ambient, $\Delta T_J(°C)$, which is the product of the power dissipated within the LED junction, $P_D(W)$, and the thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}(°C/W)$.

$$T_J = T_A + \Delta T_J$$
$$T_J = T_A + P_D \times R\theta_{J\text{-}A} \quad (1)$$

The cathode leads (pins) of a typical LED device are the primary thermal paths for heat dissipation from the LED junction to the surrounding environment. The exceptions are TS AlGaAs lamps, that use flip chip technology (anode die attach), where the anode lead is the primary thermal path. The data sheet lists the thermal resistance LED junction-to-pin, $R\theta_{J\text{-}PIN}(°C/W)$, for each device type listed. This device thermal resistance is added to the pc board mounting assembly thermal resistance-to-ambient, $R\theta_{PC\text{-}A}(°C/W)$, to obtain the overall thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}(°C/W)$.

$$R\theta_{J\text{-}A} = R\theta_{J\text{-}PIN} + R\theta_{PC\text{-}A} \quad (2)$$

$R\theta_{J\text{-}A}$ is on a per LED chip basis for lamps, light bars, and 7-segment displays, and on a per device basis for displays with on-board ICs.

For reliable operation, it is recommended that the value of $R\theta_{PC\text{-}A}$ be designed low enough to achieve the lowest possible $R\theta_{J\text{-}A}$ to ensure the LED junction temperature does not exceed the absolute maximum value when the device is operated in the maximum surrounding ambient temperature.

Maximum Power Calculation

The maximum allowed power that may be dissipated within an LED junction, P_{MAX}, is determined by multiplying the maximum rated dc current by the forward voltage for that current, determined from Figure 2.

$$P_{MAX} = I_{DC}MAX \times V_F \quad (3)$$

Derating vs. Temperature

The drive current derating vs. temperature, Figure 5, is a function of drive current, $T_J MAX$, and $R\theta_{J\text{-}A}$. Typically derating curves are given from two ambient temperatures, $T_A = 50°C$ (solid line) and 70°C (dashed line). The derating curves are lines of $T_J MAX$ with slopes equal to the specific maximum $R\theta_{J\text{-}A}$ values indicated, intersecting the temperature axis at the maximum LED junction temperature point with zero current. Operation of the LED device at a particular drive current should be at or below a derating curve with a thermal resistance-to-ambient at or less than the maximum value indicated for that curve.

Current Limiting

An LED is a current operated device, and therefore, requires some kind of current limiting incorporated into the drive circuit. This current limiting typically takes the form of a current limiter resistor, R, placed in series with the LED. The forward voltage characteristic of Figure 2 is used to calculate the value of the series current limiter resistor.

$$R = \frac{V_{CC} - V_{SAT} - V_F}{I_{PEAK}} \quad (4)$$

Where:

- V_{CC} = Power supply voltage.
- V_{SAT} = Saturation voltage of driver transistor(s).
- V_F = Forward voltage of the LED at I_{PEAK}.
- I_{PEAK} = The peak drive current through the LED.

Light Output

The luminous intensity at $T_A = 25°C$ for a particular dc drive condition is determined using the relative luminous intensity factor from Figure 3.

$$I_V\,(dc) = [I_V(25°C)]\,[\text{Relative Intensity Factor}] \quad (5)$$

Where: I_V (25°C) is obtained from the data sheet.

For pulsed drive conditions, the time average luminous intensity is determined from the relative efficiency characteristic, η_V, presented in Figure 4. (Note: Not all data sheets include relative efficiency data.)

$$I_V\,(\text{time average}) = [I_V\,(25°C)]\,[I_{AVG}/I_F]\,[\eta_V] \quad (6)$$

Where:

- I_V (25°C) = Data sheet luminous intensity value.

I_{AVG} = The time average operating current.

I_F = The current where the data sheet luminous intensity is specified.

η_v = Relative efficiency factor for the peak drive current, I_{PEAK}.

The calculated luminous intensity value at $T_A = 25°C$ can be adjusted for a different operating ambient temperature by the following exponential equation, and using the k factor for the specific LED.

$$I_V(T_A) = I_V(25°C)e^{[k(T_A - 25°C)]} \quad (7)$$

LED	k
Standard Red	-0.0188/°C
High Efficiency Red	-0.0131/°C
Yellow	-0.0112/°C
Green	-0.0104/°C
DH AS AlGaAs	-0.0095/°C
TS AlGaAs	-0.0130/°C
AlInGaP	-0.0100/°C
TS AlInGaP	-0.0100/°C

Pulsed Operation vs. DC Operation

When operating an LED device under dc drive conditions, the LED junction temperature is a linear function of the dc power dissipation multiplied by $R\theta_{J\text{-}A}$. The light output is proportional to the dc drive current by the luminous intensity factor of Figure 3 and as expressed in Equation 5.

For best pulsed operation and overall light output performance, a rectangular current waveform with a refresh rate equal to or greater than 100 Hz is strongly recommended. Sinusoidal waveforms are not generally recommended, as the rms power will exceed that of a rectangular current waveform with the same peak current value. If a sinusoidal current waveform is used, the peak current should not exceed the maximum dc current rating. Sinusoidal waveforms produce less than two thirds the light output of an equivalent rectangular pulse, and at 50 or 60 Hz, are not fast enough to prevent observable flicker.

When operating an LED device in pulsed current mode, it is the peak junction temperature, not the average junction temperature, that governs the performance of the device. At refresh rates below 1000 Hz (the number of times per second a device is pulsed), the peak junction temperature is higher than the average junction temperature. As a result, the allowed time average currents for refresh rates between 100 Hz and 1000 Hz are less than those permitted at 1000 Hz, as can be seen by the 100 Hz and 300 Hz curves of Figure 6.

Design Steps

In order to determine the derated drive conditions from the data sheet for an elevated ambient temperature, the value for $R\theta_{J\text{-}A}$ must be determined. Once the value for $R\theta_{J\text{-}A}$ has been established, the required current derating can be determined for safe operation at the elevated temperature directly from Figure 5. The basic design steps are:

1. Determine $R\theta_{J\text{-}A}$.
2. Calculate the required value for $R\theta_{PC\text{-}A}$ for the pc board mounting configuration.
3. Determine the maximum allowable dc drive current for the operating ambient temperature.
4. Calculate the LED chip power dissipation to be sure it will not cause T_J to exceed the absolute maximum value.
5. Calculate the value of the current limiting resistor.
6. Determine the luminous intensity at 25°C and at the elevated ambient temperature.

The example calculations in this application note use representative data typically contained in LED lamp data sheets. The purpose of the calculations is to ensure reliable operation of an LED lamp when operated at an elevated ambient temperature. For the example calculations, a sample T-1 3/4 LED lamp is used, with 0.45 mm (0.018 in.) square leads and the following data sheet parameters:

Typical Luminous Intensity at 20 mA, $I_V(25°C) = 2.0$ cd (candela).
Maximum Peak Forward Current = 300 mA.
Maximum Average Forward Current = 30 mA (I_{PEAK} = 300 mA).
Maximum dc Forward Current = 50 mA.
Maximum LED Junction Temperature = 110°C.
$R\theta_{J\text{-}PIN}$ = 260°C/W

DC Design Example

In this example, the operating ambient temperature is assumed to be $T_A = 60°C$.

Step 1. For this example, the value for $R\theta_{J\text{-}A}$ has been established to be 500°C/W.

From Figure 4,
η_v (200 mA) = 0.82.
I_V (25°C) =
[2.0 cd] [38 mA/20 mA] [0.82]
I_V (25°C) = [2.0 cd] [1.56]
I_V (25°C) = **3.12 cd**

I_V (50°C) =
(3.12 cd) $e^{-0.0130/°C(50 - 25°C)}$
I_V (50°C) = (3.1 cd) (0.723)
I_V (50°C)) = **2.26 cd**

Pulsed parameter summary:
T_A = 50°C
$R\theta_{PC\text{-}A}$ = 240°C/W
I_{PEAK} = 200 mA
I_{AVG} = 38 mA
f = 1000 Hz; DF = 19.0%
T_J = 103°C
R = 10 Ω, 1/4 W
I_V (25°C) = 3.12 cd
I_V (60°C) = 2.26 cd

DC Operation is Better than Pulsed Operation for Light Output

It is always better to drive an LED device with a high dc current to obtain the necessary light output to be viewed by a human observer than to pulse drive the LED. Using a high peak current and a low duty factor to pulse drive an LED device produces less time average light output than by using a high dc drive current.

There are only two reasons for pulse driving an LED device:
1) To strobe an LED array to form messages of changing characters or symbols to be viewed by human observers.
2) To obtain a peak pulse of light to be received by a photodetector in a non-visual emitter/ detector application. In this case, the high peak pulse of light produces a high peak photocurrent output from the photodetector.

Operation Without Current Derating

LED lamp and display devices may be operated in elevated ambient temperatures without current derating only when the pc board mounting configuration is designed for a sufficiently low thermal resistance-to-ambient. The criterion is that the LED junction temperature must not exceed the T_JMAX value for the device. This low thermal resistance design may include such items as a maximum metalized pc board and possible heat sinking to ensure adequate heat dissipation. Operation above the Absolute Maximum Current Ratings is not recommended.

The necessary thermal resistance requirements for operation without current derating are calculated for the maximum power dissipation using the Absolute Maximum DC Current.

1. Calculate the maximum power dissipation, if not provided on the data sheet.

2. Using Equation 1, calculate the allowable ΔT_J rise above the elevated ambient temperature.

3. Calculate the required thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}$.

$$R\theta_{J\text{-}A} = \Delta T_J / P_{MAX} \qquad (8)$$

4. Calculate the allowable thermal resistance pc board-to-ambient using Equation 2.

Using the above sample LED lamp, the following example calculations determine the thermal resistance requirements for operating at T_A = 80°C without dc current derating.

Step 1.
V_F (50 mA) = 2.05 V.

From Equation 3:
P_{MAX} = (0.050 A) (2.05 V)
P_{MAX} = **0.103 W**

Step 2.
From Equation 1:
ΔT_J = 110°C - 80°C
ΔT_J = **30°C**

Step 3.
Using Equation 8:
$R\theta_{J\text{-}A}$ = 30°C / 0.103 W
$R\theta_{J\text{-}A}$ = **291°C/W**

Step 4.
From Equation 2:
$R\theta_{PC\text{-}A}$ = 291°C/W - 260°C/W
$R\theta_{PC\text{-}A}$ = **31°C/W**

To obtain this low a value for the pc board thermal resistance-to-ambient necessitates the use of a maximum metalized pc board, may require special heat sinking attached to the device leads, and forced air cooling. This means considerable cost is added to the design to allow for operation at 80°C without current derating.

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Japan: (81 3) 3335-8152
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Data Subject to Change

Obsoletes 5953-0419
Printed in U.S.A. 5091-9704E (2/98)

Step 2.
From Equation 2:
$R\theta_{PC\text{-}A}$ = (500 - 260°C/W)
$R\theta_{PC\text{-}A}$ = **240°C/W**

The pc board mounting assembly should be designed to provide this value of thermal resistance to ambient, or less, for reliable operation of the LED device.

Step 3.
From Figure 5, the following are determined:
1) $R\theta_{PC\text{-}A}$ at 500°C/W is less than the maximum $R\theta_{PC\text{-}A}$ shown for the solid line derating curve.
2) The maximum allowable dc current at T_A of 60°C = **42 mA**.

Step 4.
Calculation of the power dissipation for 42 mA drive current using Equation 3.
From Figure 2, V_F (42 mA) = 1.95 volts.
P(W) =
(0.042 A) (1.95 V) = 0.082 W
P(W) = **82 mW**

Using Equation 1 for LED junction temperature:

T_J = 60°C + (0.082 W) (500°C/W)
T_J = **101°C**, less than the maximum allowable 110°C.

Step 5.
Equation 4 is used to calculate the value of the current limiting resistor. A 5 volt power supply is used. One switching transistor is used to drive the LED lamp with a saturation of 0.1 volts.

$$R = \frac{5.0\text{ V} - 0.1\text{ V} - 1.95\text{ V}}{0.042\text{ A}}$$

R = **70 Ω**

Resistor power rating should be 2x the actual power dissipation:

$P_R = I^2 \times R$ = (0.042 A)^2 x 70 Ω
P_R = **0.123 W**

Thus, use a 1/4 watt 70 Ω resistor.

Step 6.
The luminous intensity at T_A = 25°C is determined from Figure 3 and Equation 5:

From Figure 3, the relative luminous intensity factor at 42 mA = 2.0.

I_V (25 °C) = (2.0 cd) (2.0)
I_V (25 °C) = **4.0 cd**

At the operating temperature of 60°C, the luminous intensity is calculated using Equation 7 and the appropriate k value. For this example, k = -0.0130/°C

I_V (60°C) =
(4.0 cd) $e^{-0.0130/°C(60 - 25°C)}$
I_V (60°C) = (4.0 cd) (0.634)
I_V (60°C) = **2.54 cd**

DC parameter summary:
T_A = 60°C
$R\theta_{PC\text{-}A}$ = 240°C/W
I_F (dc) = 42 mA
T_J = 101°C
R = 70 Ω, 1/4 W
I_V (25°C) = 4.0 cd
I_V (60°C) = 2.54 cd

Pulsed Mode Design Example
In this example, T_A = 50°C, and the above LED lamp is to be pulsed with a refresh rate of 1000 Hz at 200 mA peak drive current.

Steps 1 and 2. The $R\theta_{J\text{-}A}$ and $R\theta_{PC\text{-}A}$ values are the same as determined in the above DC Design Example.

Step 3.
From Figure 6, at a refresh rate of 1000 Hz and I_{PEAK} of 200 mA, the maximum allowable time average current, I_{AVG}, = **38 mA**.

The on-time duty factor, DF is:
DF = I_{AVG} / I_{PEAK}
DF = 38 mA / 200 mA = 0.190
DF = **19.0%**

Step 4.
From Figure 2, V_F (200 mA) = 2.8 volts. The time average power is:

P = I_{PEAK} x V_F (I_{PEAK}) x DF
P = (0.200 A) (2.8 V) (0.190)
P = **0.106 W**

Using Equation 1 for LED junction temperature:
T_J =
50°C + (0.106 W) (500°C/W)
T_J = **103°C**, less than the maximum allowable 110°C.

Step 5.
At 200 mA, the driver transistor saturation is 0.2 volts.

$$R = \frac{5.0\text{ V} - 0.2\text{ V} - 2.8\text{ V}}{0.200\text{ A}}$$

R = **10 Ω**

Resistor power rating should be 2x the time average power dissipation:

P_R = (I_{PEAK})^2 x R x DF
= (0.200 A)^2(10 Ω)(0.190)
P_R = **0.076 W**

Thus, use a 1/4 watt 10 Ω resistor.

Step 6.
The time average luminous intensity at T_A = 25°C is determined using Equation 6 and the relative efficiency factor from Figure 4.

HEWLETT® PACKARD

Operational Considerations for LED Lamps and Display Devices

Application Note 1005

In the design of a drive circuit for an LED lamp, an LED light bar, or an LED 7-segment display, the objective is to achieve optimum light output, power dissipation, reliability, and operating life. The performance capabilities of each LED device are presented in the device data sheet. The data sheet contains tabular data and graphs that describe the optical and electrical characteristics of the LED device, and Absolute Maximum Ratings which are the maximum operating capabilities of the device. A thorough understanding of how to use this information is the basis for achieving an optimum design.

This application note presents an in-depth discussion of the use of the optical and electrical information contained in an LED device data sheet. Design examples for dc and pulsed operation are presented. The calculated results for each example are in **Bold Type** for identification.

Typical Data Sheet Information

Data sheets typically contain three tables of data. Usually for LED lamp devices the first table is titled **Device Selection Guide** or **Axial Luminous Intensity and Viewing Angle at T_A = 25°C** and presents the basic optical characteristics of the devices listed in the data sheet. The luminous intensity, I_V, both minimum and typical values, are listed in this table. This table is used as a device selection guide.

The next table is titled **Absolute Maximum Ratings at T_A = 25°C**, containing maximum peak, dc and average currents, maximum transient current, operating and storage temperature range, and the absolute maximum LED junction temperature. These are the maximum allowed operating conditions for all the devices in the data sheet.

The third table, titled **Electrical/Optical Characteristics at T_A = 25°C**, contains the electrical data, and some optical data, that are used to determine the operating conditions for the device. The forward voltage, V_F, and device thermal resistance, $R\theta_{J\text{-}PIN}$, used in operating condition calculations, are listed in this table.

The graphs usually contained in a lamp data sheet used to determine operational conditions are:

Figure 1. Relative Intensity vs. Wavelength. (not shown here)

Figure 2. Forward Current vs. Forward Voltage.

Figure 3. Relative Luminous Intensity vs. DC Forward Current.

Figure 4. Relative Efficiency vs. Peak Current. (This figure is not included on all data sheets.)

Figure 5. Maximum Forward DC Current vs. Ambient Temperature.

Figure 6. Maximum Average Current vs. Peak Forward Current.

Figure 7. Relative Luminous Intensity vs. Angular Displacement. (not shown here)

Design Criteria

The two criteria that establish the operating limits are the maximum

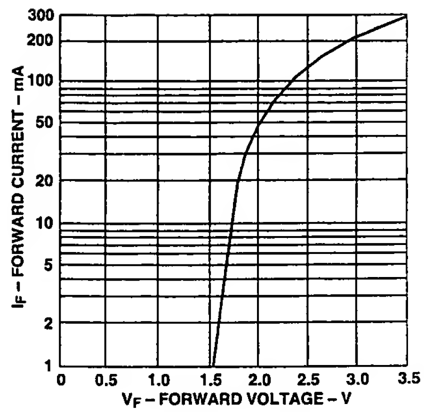

Figure 2. Forward Current vs. Forward Voltage.

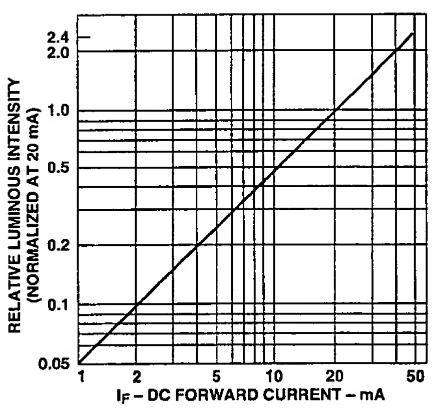

Figure 3. Relative Luminous Intensity vs. DC Forward Current.

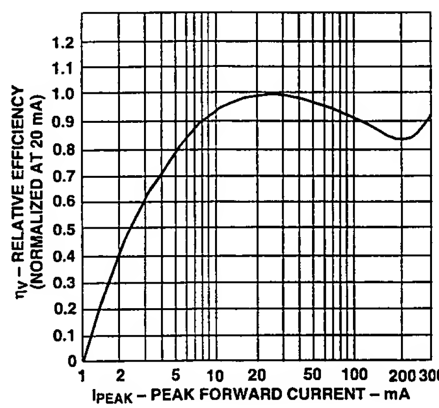

Figure 4. Relative Efficiency vs. Peak Forward Current.

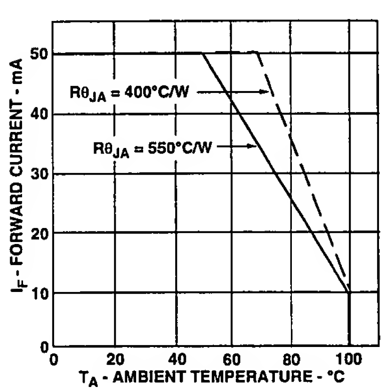

Figure 5. Maximum Forward DC Current vs. Ambient Temperature. Derating Based on T_JMAX = 110°C.

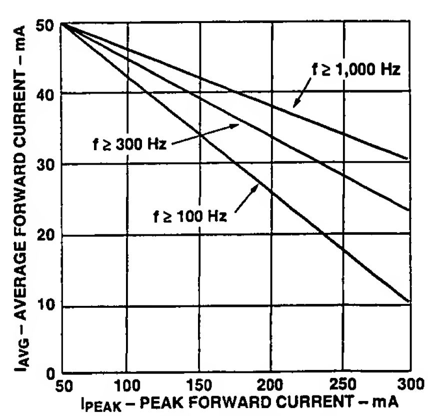

Figure 6. Maximum Average Current vs. Peak forward Current.

drive currents and the absolute maximum LED junction temperature, T_JMAX. The maximum drive currents have been established to ensure long operating life. The absolute maximum LED junction temperature is a device package limitation that must not be exceeded.

Thermal Resistance

The LED junction temperature, $T_J(°C)$, is the sum of the ambient temperature, $T_A(°C)$, and the temperature rise of the LED junction above ambient, $\Delta T_J(°C)$, which is the product of the power dissipated within the LED junction, $P_D(W)$, and the thermal resistance LED junction-to-ambient, $R\theta_{J-A}(°C/W)$.

$$T_J = T_A + \Delta T_J$$
$$T_J = T_A + P_D \times R\theta_{J-A} \quad (1)$$

The cathode leads (pins) of a typical LED device are the primary thermal paths for heat dissipation from the LED junction to the surrounding environment. The exceptions are TS AlGaAs lamps, that use flip chip technology (anode die attach), where the anode lead is the primary thermal path. The data sheet lists the thermal resistance LED junction-to-pin, $R\theta_{J-PIN}(°C/W)$, for each device type listed. This device thermal resistance is added to the pc board mounting assembly thermal resistance-to-ambient, $R\theta_{PC-A}(°C/W)$, to obtain the overall thermal resistance LED junction-to-ambient, $R\theta_{J-A}(°C/W)$.

$$R\theta_{J-A} = R\theta_{J-PIN} + R\theta_{PC-A} \quad (2)$$

$R\theta_{J-A}$ is on a per LED chip basis for lamps, light bars, and 7-segment displays, and on a per device basis for displays with on-board ICs.

For reliable operation, it is recommended that the value of $R\theta_{PC-A}$ be designed low enough to achieve the lowest possible $R\theta_{J-A}$ to ensure the LED junction temperature does not exceed the absolute maximum value when the device is operated in the maximum surrounding ambient temperature.

Maximum Power Calculation

The maximum allowed power that may be dissipated within an LED junction, P_{MAX}, is determined by multiplying the maximum rated dc current by the forward voltage for that current, determined from Figure 2.

$$P_{MAX} = I_{DC}MAX \times V_F \quad (3)$$

Derating vs. Temperature

The drive current derating vs. temperature, Figure 5, is a function of drive current, T_JMAX, and $R\theta_{J-A}$. Typically derating curves are given from two ambient temperatures, $T_A = 50°C$ (solid line) and 70°C (dashed line). The derating curves are lines of T_JMAX with slopes equal to the specific maximum $R\theta_{J-A}$ values indicated, intersecting the temperature axis at the maximum LED junction temperature point with zero current. Operation of the LED device at a particular drive current should be at or below a derating curve with a thermal resistance-to-ambient at or less than the maximum value indicated for that curve.

Current Limiting

An LED is a current operated device, and therefore, requires some kind of current limiting incorporated into the drive circuit. This current limiting typically takes the form of a current limiter resistor, R, placed in series with the LED. The forward voltage characteristic of Figure 2 is used to calculate the value of the series current limiter resistor.

$$R = \frac{V_{CC} - V_{SAT} - V_F}{I_{PEAK}} \quad (4)$$

Where:

V_{CC} = Power supply voltage.
V_{SAT} = Saturation voltage of driver transistor(s).
V_F = Forward voltage of the LED at I_{PEAK}.
I_{PEAK} = The peak drive current through the LED.

Light Output

The luminous intensity at $T_A = 25°C$ for a particular dc drive condition is determined using the relative luminous intensity factor from Figure 3.

$$I_V\,(dc) = [I_V(25°C)]\,[\text{Relative Intensity Factor}] \quad (5)$$

Where: I_V (25°C) is obtained from the data sheet.

For pulsed drive conditions, the time average luminous intensity is determined from the relative efficiency characteristic, η_V, presented in Figure 4. (Note: Not all data sheets include relative efficiency data.)

$$I_V\,(\text{time average}) = [I_V\,(25°C)]\,[I_{AVG}/I_F]\,[\eta_V] \quad (6)$$

Where:

I_V (25°C) = Data sheet luminous intensity value.

I_{AVG} = The time average operating current.
I_F = The current where the data sheet luminous intensity is specified.
η_v = Relative efficiency factor for the peak drive current, I_{PEAK}.

The calculated luminous intensity value at T_A = 25°C can be adjusted for a different operating ambient temperature by the following exponential equation, and using the k factor for the specific LED.

$$I_V(T_A) = I_V(25°C)e^{[k(T_A - 25°C)]} \quad (7)$$

LED	k
Standard Red	-0.0188/°C
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TS AlGaAs	-0.0130/°C
AlInGaP	-0.0100/°C
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When operating an LED device under dc drive conditions, the LED junction temperature is a linear function of the dc power dissipation multiplied by $R\theta_{J-A}$. The light output is proportional to the dc drive current by the luminous intensity factor of Figure 3 and as expressed in Equation 5.

For best pulsed operation and overall light output performance, a rectangular current waveform with a refresh rate equal to or greater than 100 Hz is strongly recommended. Sinusoidal waveforms are not generally recommended, as the rms power will exceed that of a rectangular current waveform with the same peak current value. If a sinusoidal current waveform is used, the peak current should not exceed the maximum dc current rating. Sinusoidal waveforms produce less than two thirds the light output of an equivalent rectangular pulse, and at 50 or 60 Hz, are not fast enough to prevent observable flicker.

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Design Steps

In order to determine the derated drive conditions from the data sheet for an elevated ambient temperature, the value for $R\theta_{J-A}$ must be determined. Once the value for $R\theta_{J-A}$ has been established, the required current derating can be determined for safe operation at the elevated temperature directly from Figure 5. The basic design steps are:

1. Determine $R\theta_{J-A}$.
2. Calculate the required value for $R\theta_{PC-A}$ for the pc board mounting configuration.
3. Determine the maximum allowable dc drive current for the operating ambient temperature.
4. Calculate the LED chip power dissipation to be sure it will not cause T_J to exceed the absolute maximum value.
5. Calculate the value of the current limiting resistor.
6. Determine the luminous intensity at 25°C and at the elevated ambient temperature.

The example calculations in this application note use representative data typically contained in LED lamp data sheets. The purpose of the calculations is to ensure reliable operation of an LED lamp when operated at an elevated ambient temperature. For the example calculations, a sample T-1 3/4 LED lamp is used, with 0.45 mm (0.018 in.) square leads and the following data sheet parameters:

Typical Luminous Intensity at 20 mA, I_V (25°C) = 2.0 cd (candela).
Maximum Peak Forward Current = 300 mA.
Maximum Average Forward Current = 30 mA (I_{PEAK} = 300 mA).
Maximum dc Forward Current = 50 mA.
Maximum LED Junction Temperature = 110°C.
$R\theta_{J-PIN}$ = 260°C/W

DC Design Example

In this example, the operating ambient temperature is assumed to be T_A = 60°C.

Step 1. For this example, the value for $R\theta_{J-A}$ has been established to be 500°C/W.

Step 2.
From Equation 2:
$R\theta_{PC\text{-}A}$ = (500 - 260°C/W)
$R\theta_{PC\text{-}A}$ = **240°C/W**

The pc board mounting assembly should be designed to provide this value of thermal resistance to ambient, or less, for reliable operation of the LED device.

Step 3.
From Figure 5, the following are determined:
1) $R\theta_{PC\text{-}A}$ at 500°C/W is less than the maximum $R\theta_{PC\text{-}A}$ shown for the solid line derating curve.
2) The maximum allowable dc current at T_A of 60°C = **42 mA.**

Step 4.
Calculation of the power dissipation for 42 mA drive current using Equation 3.
From Figure 2, V_F (42 mA) = 1.95 volts.
P(W) =
(0.042 A) (1.95 V) = 0.082 W
P(W) = **82 mW**

Using Equation 1 for LED junction temperature:

T_J = 60°C + (0.082 W) (500°C/W)
T_J = **101°C**, less than the maximum allowable 110°C.

Step 5.
Equation 4 is used to calculate the value of the current limiting resistor. A 5 volt power supply is used. One switching transistor is used to drive the LED lamp with a saturation of 0.1 volts.

$$R = \frac{5.0\text{ V} - 0.1\text{ V} - 1.95\text{ V}}{0.042\text{ A}}$$

R = **70 Ω**

Resistor power rating should be 2x the actual power dissipation:

$P_R = I^2 \times R = (0.042\text{ A})^2 \times 70\ \Omega$
P_R = **0.123 W**

Thus, use a 1/4 watt 70 Ω resistor.

Step 6.
The luminous intensity at T_A = 25°C is determined from Figure 3 and Equation 5:

From Figure 3, the relative luminous intensity factor at 42 mA = 2.0.

I_V (25 °C) = (2.0 cd) (2.0)
I_V (25 °C) = **4.0 cd**

At the operating temperature of 60°C, the luminous intensity is calculated using Equation 7 and the appropriate k value. For this example, k = -0.0130/°C

I_V (60°C) =
(4.0 cd) $e^{-0.0130/°C\,(60\,-\,25°C)}$
I_V (60°C) = (4.0 cd) (0.634)
I_V (60°C) = **2.54 cd**

DC parameter summary:
T_A = 60°C
$R\theta_{PC\text{-}A}$ = 240°C/W
I_F (dc) = 42 mA
T_J = 101°C
R = 70 Ω, 1/4 W
I_V (25°C) = 4.0 cd
I_V (60°C) = 2.54 cd

Pulsed Mode Design Example

In this example, T_A = 50°C, and the above LED lamp is to be pulsed with a refresh rate of 1000 Hz at 200 mA peak drive current.

Steps 1 and 2. The $R\theta_{J\text{-}A}$ and $R\theta_{PC\text{-}A}$ values are the same as determined in the above DC Design Example.

Step 3.
From Figure 6, at a refresh rate of 1000 Hz and I_{PEAK} of 200 mA, the maximum allowable time average current, I_{AVG} , = **38 mA.**

The on-time duty factor, DF is:
DF = I_{AVG} / I_{PEAK}
DF = 38 mA / 200 mA = 0.190
DF = **19.0%**

Step 4.
From Figure 2, V_F (200 mA) = 2.8 volts. The time average power is:

P = I_{PEAK} x V_F (I_{PEAK}) x DF
P = (0.200 A) (2.8 V) (0.190)
P = **0.106 W**

Using Equation 1 for LED junction temperature:
T_J =
50°C + (0.106 W) (500°C/W)
T_J = **103°C**, less than the maximum allowable 110°C.

Step 5.
At 200 mA, the driver transistor saturation is 0.2 volts.

$$R = \frac{5.0\text{ V} - 0.2\text{ V} - 2.8\text{ V}}{0.200\text{ A}}$$

R = **10 Ω**

Resistor power rating should be 2x the time average power dissipation:

$P_R = (I_{PEAK})^2 \times R \times DF$
$= (0.200\text{ A})^2 (10\ \Omega) (0.190)$
P_R = **0.076 W**

Thus, use a 1/4 watt 10 Ω resistor.

Step 6.
The time average luminous intensity at T_A = 25°C is determined using Equation 6 and the relative efficiency factor from Figure 4.

From Figure 4,
η_V (200 mA) = 0.82.
I_V (25°C) =
[2.0 cd] [38 mA/20 mA] [0.82]
I_V (25°C) = [2.0 cd] [1.56]
I_V (25°C) = **3.12 cd**

I_V (50°C) =
(3.12 cd) $e^{-0.0130/°C(50 - 25°C)}$
I_V (50°C) = (3.1 cd) (0.723)
I_V (50°C)) = **2.26 cd**

Pulsed parameter summary:
T_A = 50°C
$R\theta_{PC\text{-}A}$ = 240°C/W
I_{PEAK} = 200 mA
I_{AVG} = 38 mA
f = 1000 Hz; DF = 19.0%
T_J = 103°C
R = 10 Ω, 1/4 W
I_V (25°C) = 3.12 cd
I_V (60°C) = 2.26 cd

DC Operation is Better than Pulsed Operation for Light Output

It is always better to drive an LED device with a high dc current to obtain the necessary light output to be viewed by a human observer than to pulse drive the LED. Using a high peak current and a low duty factor to pulse drive an LED device produces less time average light output than by using a high dc drive current.

There are only two reasons for pulse driving an LED device:
1) To strobe an LED array to form messages of changing characters or symbols to be viewed by human observers.
2) To obtain a peak pulse of light to be received by a photodetector in a non-visual emitter/detector application. In this case, the high peak pulse of light produces a high peak photocurrent output from the photodetector.

Operation Without Current Derating
LED lamp and display devices may be operated in elevated ambient temperatures without current derating only when the pc board mounting configuration is designed for a sufficiently low thermal resistance-to-ambient. The criterion is that the LED junction temperature must not exceed the T_JMAX value for the device. This low thermal resistance design may include such items as a maximum metalized pc board and possible heat sinking to ensure adequate heat dissipation. Operation above the Absolute Maximum Current Ratings is not recommended.

The necessary thermal resistance requirements for operation without current derating are calculated for the maximum power dissipation using the Absolute Maximum DC Current.

1. Calculate the maximum power dissipation, if not provided on the data sheet.

2. Using Equation 1, calculate the allowable ΔT_J rise above the elevated ambient temperature.

3. Calculate the required thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}$.

$$R\theta_{J\text{-}A} = \Delta T_J / P_{MAX} \qquad (8)$$

4. Calculate the allowable thermal resistance pc board-to-ambient using Equation 2.

Using the above sample LED lamp, the following example calculations determine the thermal resistance requirements for operating at T_A = 80°C without dc current derating.

Step 1.
V_F (50 mA) = 2.05 V.

From Equation 3:
P_{MAX} = (0.050 A) (2.05 V)
P_{MAX} = **0.103 W**

Step 2.
From Equation 1:
ΔT_J = 110°C - 80°C
ΔT_J = **30°C**

Step 3.
Using Equation 8:
$R\theta_{J\text{-}A}$ = 30°C / 0.103 W
$R\theta_{J\text{-}A}$ = **291°C/W**

Step 4.
From Equation 2:
$R\theta_{PC\text{-}A}$ = 291°C/W - 260°C/W
$R\theta_{PC\text{-}A}$ = **31°C/W**

To obtain this low a value for the pc board thermal resistance-to-ambient necessitates the use of a maximum metalized pc board, may require special heat sinking attached to the device leads, and forced air cooling. This means considerable cost is added to the design to allow for operation at 80°C without current derating.

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LIGHT EMITTING DIODES

AN INTRODUCTION

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7 APPLICATIONS

7-1 General aspects

Because light emitting diodes are solid state, semiconductor light sources, they have some specific properties in common with other semiconductor devices like transistors or integrated circuits. Some general features of LEDs and other semiconductor devices are small size, low weight, high mechanical stability, low temperature sensitivity, high reliability, long operating lifetime, and last but not least, low price. As electrical devices, LEDs are characterized by low operating voltage, medium current, and high speed. From an optical point of view, the most important properties of LEDs can be summarized as follows: LEDs are active emitters of nearly monochromatic light with highly saturated colors.

From this set of properties some specific fields of application can be derived, which are treated in detail in the following parts of this chapter. Only a few general remarks will be made here. LEDs are mostly used at the periphery of electronic equipment of all kind. Interfacing LEDs to electronics is especially easy, because their driving requirements can be easily fulfilled by standard transistors and integrated circuits. This property is decisive for the bulk of LED applications. Typical examples are status indicators, displays for entertainment electronic equipment, and displays for measuring equipment. LEDs are also preferred to other display tech-

nologies in rough environments and where high reliability is imperative.

On the other hand, the properties of LEDs define also the limits of their applicability. For example, LEDs are not well suited for general illumination purposes, because their brightness is still inferior to other light sources, and because white light can hardly be achieved (blue LEDs are less efficient than red, yellow and green devices), but is required for color-neutral illumination. LEDs are also rarely used in battery operated equipment, where power consumption is a critical factor. Here liquid crystal displays (LCD) are dominating. The relatively high power consumption, and consequently, power dissipation of LEDs renders also the realization of high resolution, flat LED screens more difficult (see section 7-3-4). For color picture displaying, the inferior brightness of blue emitters is another limitation. Other competing flat screen technologies like LCDs or plasma displays also have difficulty in displacing the cathode ray tube, which is well developed. It offers rather high performance at quite low cost.

7-2 Driving of LEDs

7-2-1 Current limiting

The I-V characteristics of LEDs are those of normal pn diodes: in the forward direction, which is the normal operating mode, the current remains rather small until the voltage amounts to approximately E_g/e, which is about 1.9 V for red LEDs, 2.0 V for orange, 2.1 V for yellow, and 2.2 V for green. Around these voltages the current rises exponentially (see chapter 1). Because the brightness of an LED is determined by the current flowing through the device, it is the

current which has to be defined during operation. If an LED is driven by a voltage source, its brightness is very sensitive to small voltage fluctuations, due to the steep I-V characteristics. Therefore, some means for current limitation has to be provided. Two examples for current definition in LED circuits are shown in Fig. 7-1. The simplest possibility is a resistor in series to the LED (Fig. 7-1, left). Here the current through the LED (I_{LED}) is defined by the intersection of the LED characteristics with the straight line given by (operating voltage minus LED voltage) divided by resistance, which is (5 volts-V_{LED})/150 Ω in the example shown. As can be seen easily, the LED current is now far less sensitive against voltage changes. In most practical applications the value of the resistor can be calculated using the simple formula:

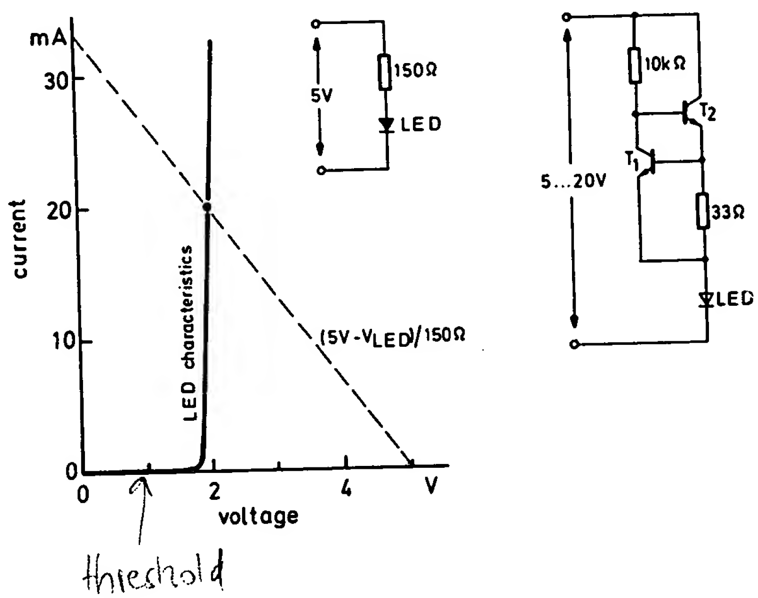

Fig. 7-1 Methods of control of LED current, left: LED with series resistor, determination of working point, right: LED with constant current source for approximately 20 mA.

$$R = (\text{operating voltage} - 2\ \text{V})/\text{LED current} \qquad (7\text{-}1)$$

because the forward voltage required for a normal operating current is roughly 2 volts for all types of LEDs.

If large voltage variations are to be expected, LEDs are driven best using a constant current source. For this purpose integrated circuits are available which are supplied by several manufacturers. A simple constant current source can also be realized with two transistors and two resistors as shown on the right hand of Fig. 7-1. This circuit controls the LED current via the voltage drop along the 33 Ω resistor, which is 0.66 V at 20 mA output current. If the current increases, the transistor T_1 becomes more conducting, thus diminishing the current flowing into the base of the transistor T_2. Therefore, the output current is decreased again. The value of the second resistor is determined by the minimum voltage to be expected and the base current necessary to drive T_2. In the example shown it is assumed that at least 2 V are available at this resistor (5 V minus LED voltage minus collector emitter voltage of T_2), and that 0.2 mA are sufficient to cause an output current of 20 mA, i.e. the current gain of T_2 should be at least 100. The upper voltage limit is given by the power dissipation in T_2 which is roughly 20 V times 20 mA or 0.4 W.

7-2-2 Multiplex operation

Because the light output of an LED is proportional to the operating current over a wide current range, LEDs can be driven by pulses instead of continuous current. The apparent brightness is then given by the average current. Some LED types even exhibit a superlinear current-light relationship, so that a net gain in brightness results in pulsed operation. This property is widely used in time multiplex operation of

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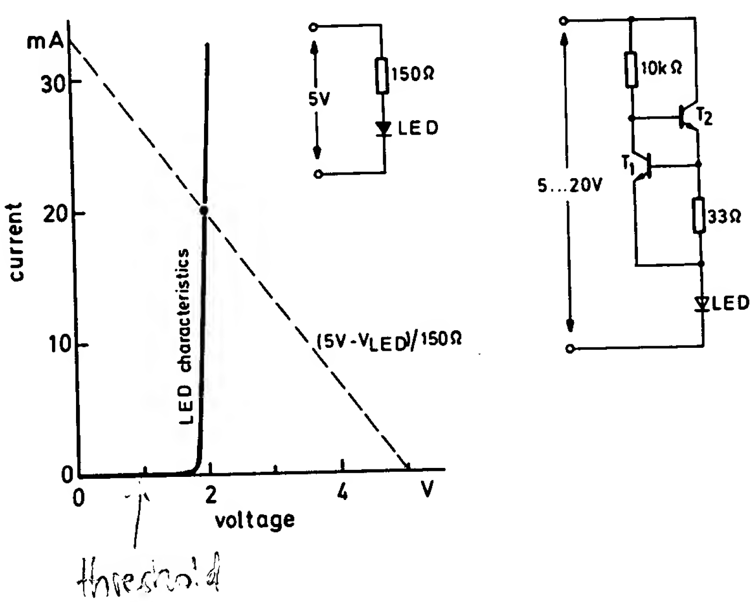

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because the forward voltage required for a normal operating current is roughly 2 volts for all types of LEDs.

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LETTER OF TESTIMONY

I, the undersigned, am an independent consultant being paid by Fiber Optic Designs Inc., to provide an unprejudiced, expert opinion as to the teaching and interpretation of U.S. Patent 5,941,626 to Yamuro entitled, "Long Light Emitting Apparatus." Specifically, I have been asked how I might interpret Yamuro's teaching on the use or omission of a resistor in his circuitry. Other than a supplied text, Basic Electronics by Bernard Grob, I have not been provided with any further information or instruction on the subject. Other than to perform the above task, I have no connection or affiliation with Fiber Optic Designs whatsoever.

I possess a degree in Political Science and have been long working as a consultant to various governments and private parties, primarily on environmental issues. From time to time I also have given expert witness or testimony, provided I felt capable of doing so. I am not trained in electrical engineering and therefore I was at first reluctant to provide this testimony. However, after reading the subject material, I consider it simple enough to understand and fully interpret. With my background as an author and editor for several technical journals, I feel confident in my ability to judge and interpret most technical writing, provided I can understand it. To me, the subject material leaves clear conclusion, without doubt, as to its meaning. My interpretation is as follows:

The resistor is used throughout the subject material. The only reference to any possible questioning of use of the resistor is in column 3, lines, 30-40. In column 3, lines 30-33, the author states, "*Therefore, the power source required for each light emitting unit **6** is 100 V. Since the required power source of 100 V is equal to the common source voltage in Japan, the resistance **8** apparently seems unnecessary.*" This comment leaves an impression that the resistor might be unnecessary in this case because the voltage used in the power source is equal to the voltage required by each light emitting unit. From a fundamental understanding that resistors would use up some of this voltage, if the resistor was kept in the circuit, the voltage to the light emitting unit would be less.

However, this notion of possibly removing the resistor is disproved by the next statement that immediately follows in lines 34-37, "*However, it is proved from experience that the apparatus is stable in function by providing the resistance **8**. Therefore, the resistance **8** is connected to the circuit shown in FIGS. 1A and 1B.*" Here, the author qualifies, using experience as the reason for proof, that the resistor provides stability by using the resistance, making the resistor needed. The author teaches that the resistor is required for the device to be stable in function. The author implies from this that an unstable device would result if the resistor were possibly removed. The author shows use of the resistor for the rest of the subject matter that follows.

Finally, in lines 37-40, the author describes how the resistor value may be determined for another case example, "*50 or less LED lamps **4**, for example 45 or 40 LED lamps, can be connected to the light emitting unit **6**. In this case, the resistance value corresponding to the potential difference from the power source **9** is set as the resistance **8**.*" Here the author states that up to 50 LED lamps may be used in the device. This implies that the use of more than 50 LED lamps is incorrect. The author then describes a case where a typical number of LED lamps would be used: 45 or 40 LED lamps. For this case, the author describes how the resistor value is determined. The computation adds the voltages of the LED lamps (e.g., 45 times 2 V or 40 times 2 V) and subtracts this sum from the voltage of the source (100 V). It is easy to see that the resistor would be determined from either 10 V or 20 V, depending on whether 45 or 40 LED lamps, respectively, were used. The case of 50 LEDs is unclear by this method, implying to me that author allows other methods to determine the resistor, and that this method is but one example.

The author's overall teaching may be summarized as follows. First, the author uses an initial case (50 LED lamps) to prove that, in all cases, a resistor must be used in this device. Second, the author teaches that a resistor is always used in his device, justifying device stability. Third, the author teaches the upper bound on the number of LED lamps to use (50 lamps). Fourth, the author gives typical examples encountered for the number of LED lamps to use (45 or 40 lamps). Finally, the author teaches a method to determine the resistor for these examples (using 10V or 20 V).

It seems obvious to me that the author justifies need for, and use of, a resistor in a circuit containing only LED lamps. In explaining the need for, and use of, the resistor in the circuit, the author cites experience as the basis of reasoning, indicating that the procedure is well known. The author teaches that it is necessary to use the resistor for the circuit to operate correctly. The author also teaches the number of LED lamps to use in the circuit, and a method of finding the resistor value for some typical examples.

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1 October 2000

Mr. David R. Allen
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Yardley, PA 19067

Dear Mr. Allen:

At your request, I have reviewed two documents and evaluated specific statements in them for consistency.

The two documents are:

- United States Patent No. 5,941,626 (24 August 1999) : Yamuro – Long Light Emitting Apparatus
- U.S. Patent Office Action, dated 22 August 2000, relative to Mr. Mark Allen's Application, Serial Number 09/339,616

Under consideration is whether Mr. Yamuro's patent permits use of his apparatus without resistors, a fundamental claim in Fiber Optic Designs' patent application for a similar apparatus.

The following appears in the section titled, "Description of the Preferred Embodiments" of Mr. Yomuro's patent. All underlinings are mine:

"The conductor is connected to one terminal of a power source plug whereas the conductor is connected to the other terminal of the power plug through a resistance...

"Since the required power source of 100V is equal to the common source voltage <u>in Japan</u>, the resistance <u>apparently</u> seems unnecessary. <u>However, it is proved from experience that the apparatus is stable in function by providing the resistance."</u>

In her rejection of Mr. Allen's request for reconsideration, U.S. Patent Office Examiner Vo noted:

"Even though this figure shows one end of the diode block being tied to the source via the resistor, by its natural layout, it fulfils applicant's definition of having this block directly ties (sic) *to the source...*

"Even though Figure 1B shows the usage of a resistor to stabilize the operation of the system, it's (sic) *teaching, however, specifically leaves the option of using this resistor to one of ordinary skill in the art...*

"Applying the design without the resistor as suggested in a massive production environment, this would mount up to a considerable saving in the production line."

A review of Mr. Yamuro's patent discloses no circuit diagram that does *not* include resistance. His statements concerning the need for resistors in his apparatus are highly qualified, as indicated in the underlined sections, above.

Nothing in the granted patent, other than the claim that resistance "apparently seems unnecessary," describes or shows the apparatus *without* the use of resistance. Further, the patent affirms that experience has shown the patented apparatus to be stable only when resistance is provided. *There is a clear implication that the patented apparatus would be unstable without the resistance*. It could therefore be argued that Mr. Yamuro's apparatus functions predictably only with the use of resistors, and that there is no proven basis for the claim that it can be used, as well, without them.

Ms. Vo's assertion, that Mr. Yamuro's apparatus would operate stably by using "ordinary skill in the art" instead of resistors, should be challenged. This is an unsatisfactory generalization that Ms. Vo, or Primary Examiner David Vu, should be asked to define specifically. Absent a satisfactory definition, you may want to pursue your application for a patent on a light-emitting apparatus that, though in some ways similar to Mr. Yomura's, differs specifically by permitting stable operation without resistors.

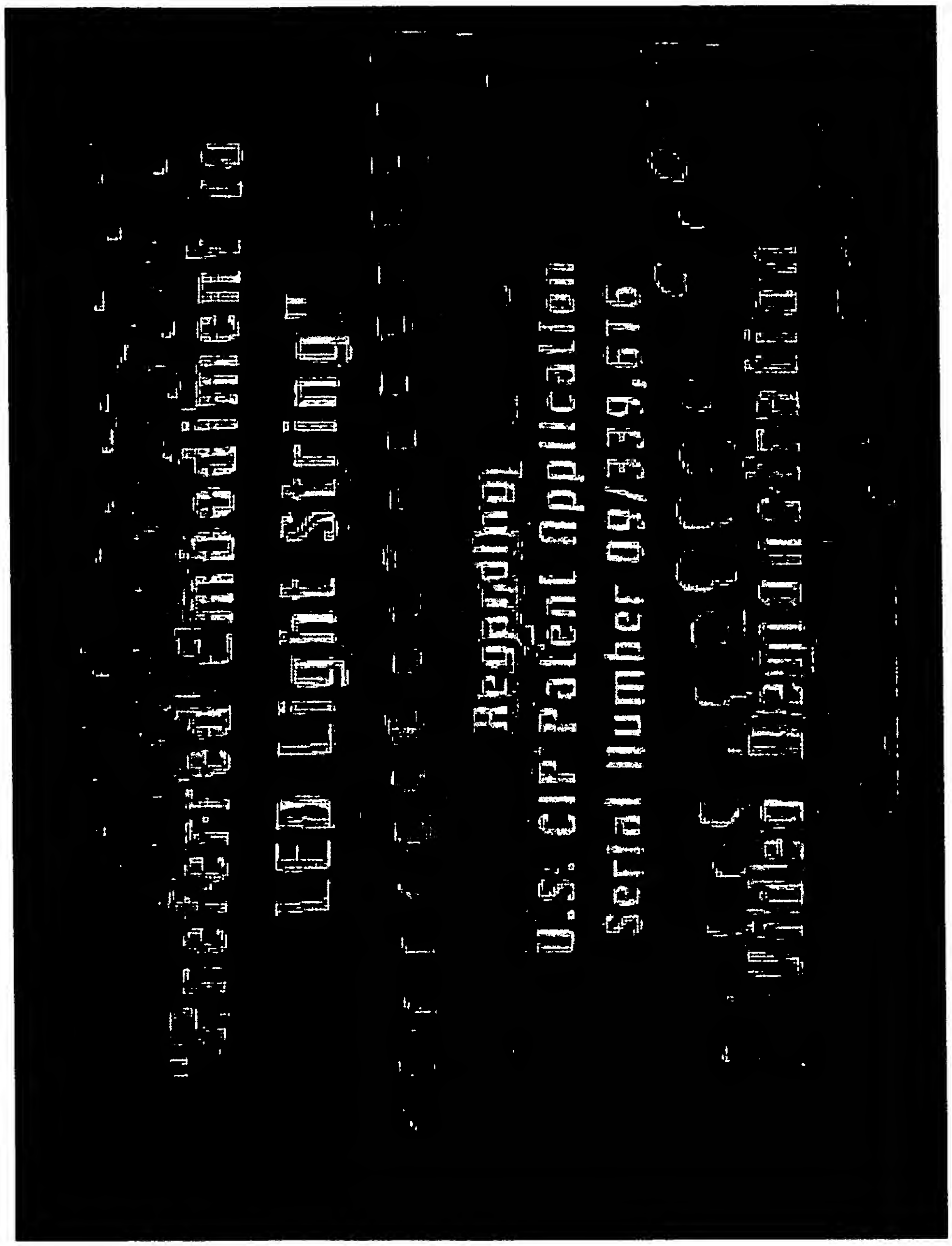
You may use this letter in any way you see fit. Should you decide to copy or forward it, readers should know that I am neither a lawyer nor an engineer. I was, however, editor-in-chief of the *AT&T Technical Journal* at Bell Laboratories for five years, and am now retired.

Sincerely,

Bert Vorchheimer

H

<u>TRANSCRIPT OF VIDEOTAPE EXPERIMENTS IN SUPPORT OF APPLICANT'S RESPONSE TO OFFICE ACTION DATED 8/29/00</u>

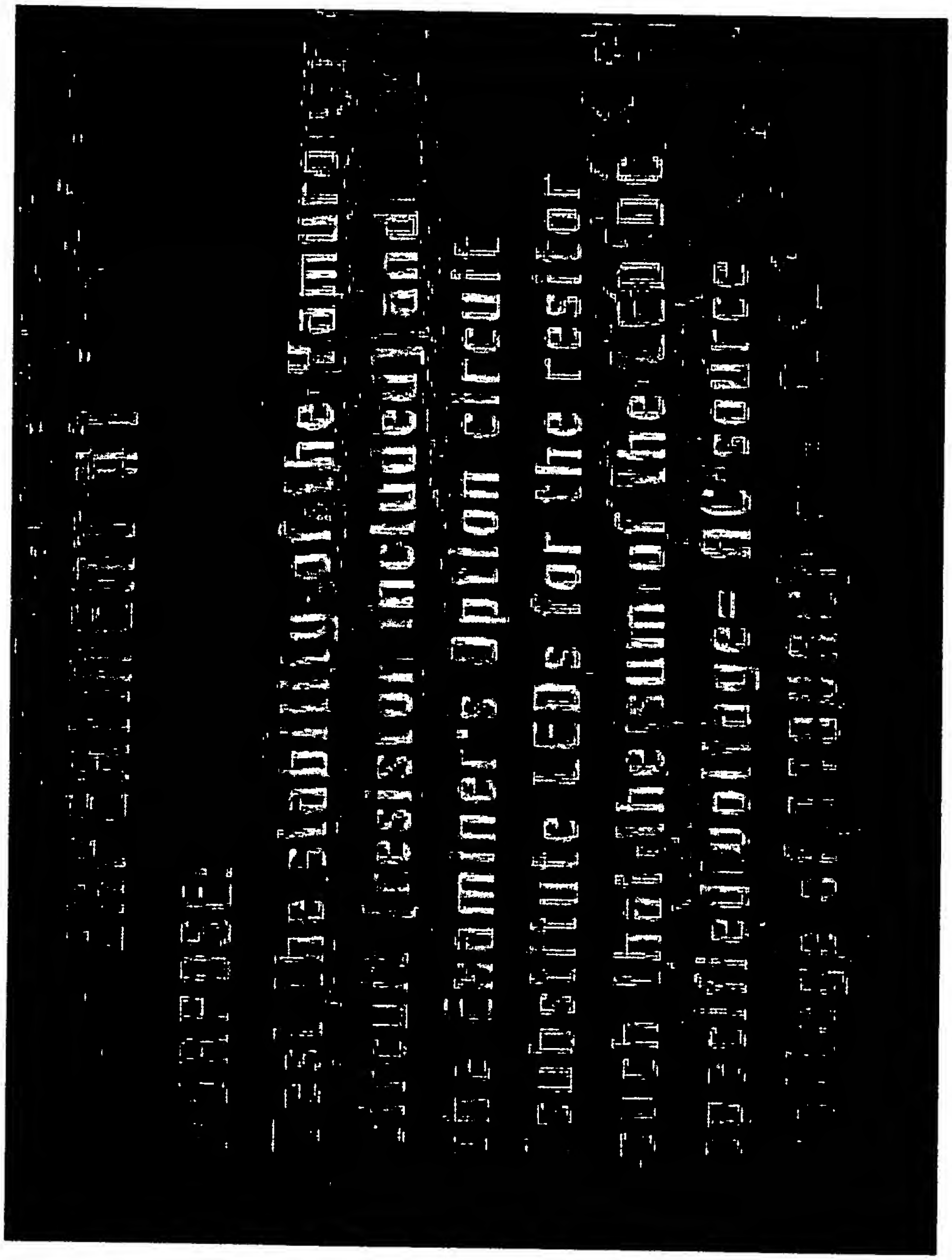

LED Light String"
Regarding
U.S. CIP Patent Application
Serial Number 09/339,616

DAVID ALLEN, President, Fiber Optics Designs, Inc.

The purpose of this videotape is to present real time experiments which address the following issues:

1. Test the applicant's theory that an LED circuit that adds the DC specified voltage of each LED to match the AC power source requires a resistor.

2. Test the examiner's theory that (a) Yamuro U.S. Patent 5942626 suggests that the resistor is optional in the circuit; (b) that the circuit is operably stable without the resistor. The experiments presented duplicate both the Yamuro circuit and the substitution of DC value LEDs for a resistor in an AC powered circuit. In all cases, the circuits are unstable and fail quickly. Thank you for your attention.


EXPERIMENT #1
PURPOSE:
Test the stability of the Yamurg
circuit (resistor included) and
the Examiner's Option circuit
(substitute LEDs for the resitor
such that the sum of the LED DC
specified voltage= AC source
voltage of 117VAC)

METHOD:

Duplicate the Yamuro circuit by building an equivalent circuit using U.S. AC source voltage...Experimental Circuit is identical to Yamuro's circuit since 50 2VDC LEDs + 500 Ohm resistor @ 110 VAC (experiment) = 45 2VDC LEDs + 500 Ohm resistor @ 100VAC (Yamuro Example).

LEDs Used (Manufacturer's Specifications):

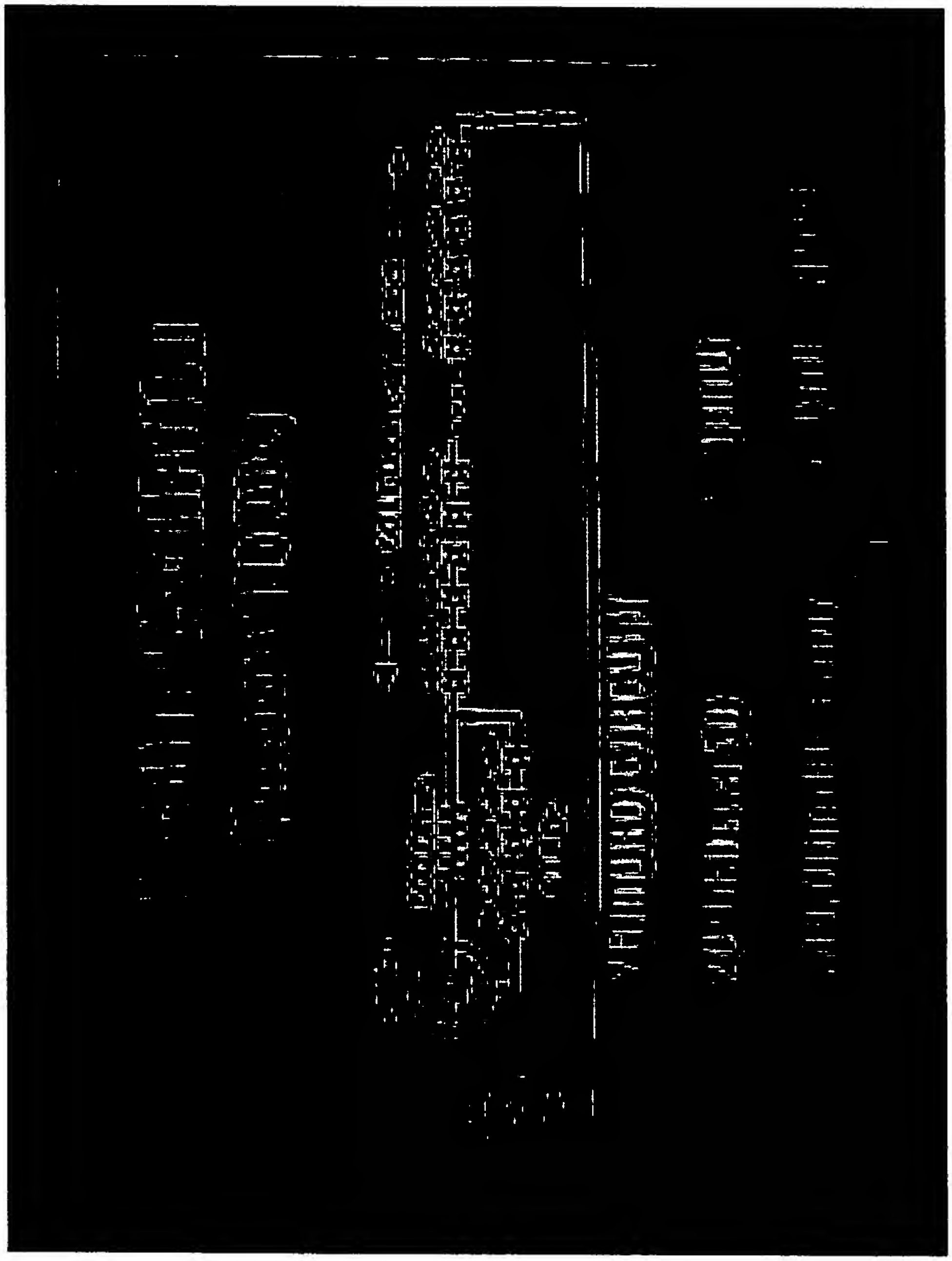
2.0 Vf DC at 20mA (typical)

2.4 Vf DC at 20mA (maximum)

Resistor Used: 500 Ohms

10 Volts/0.02 Amps (typical) = 500 Ohms

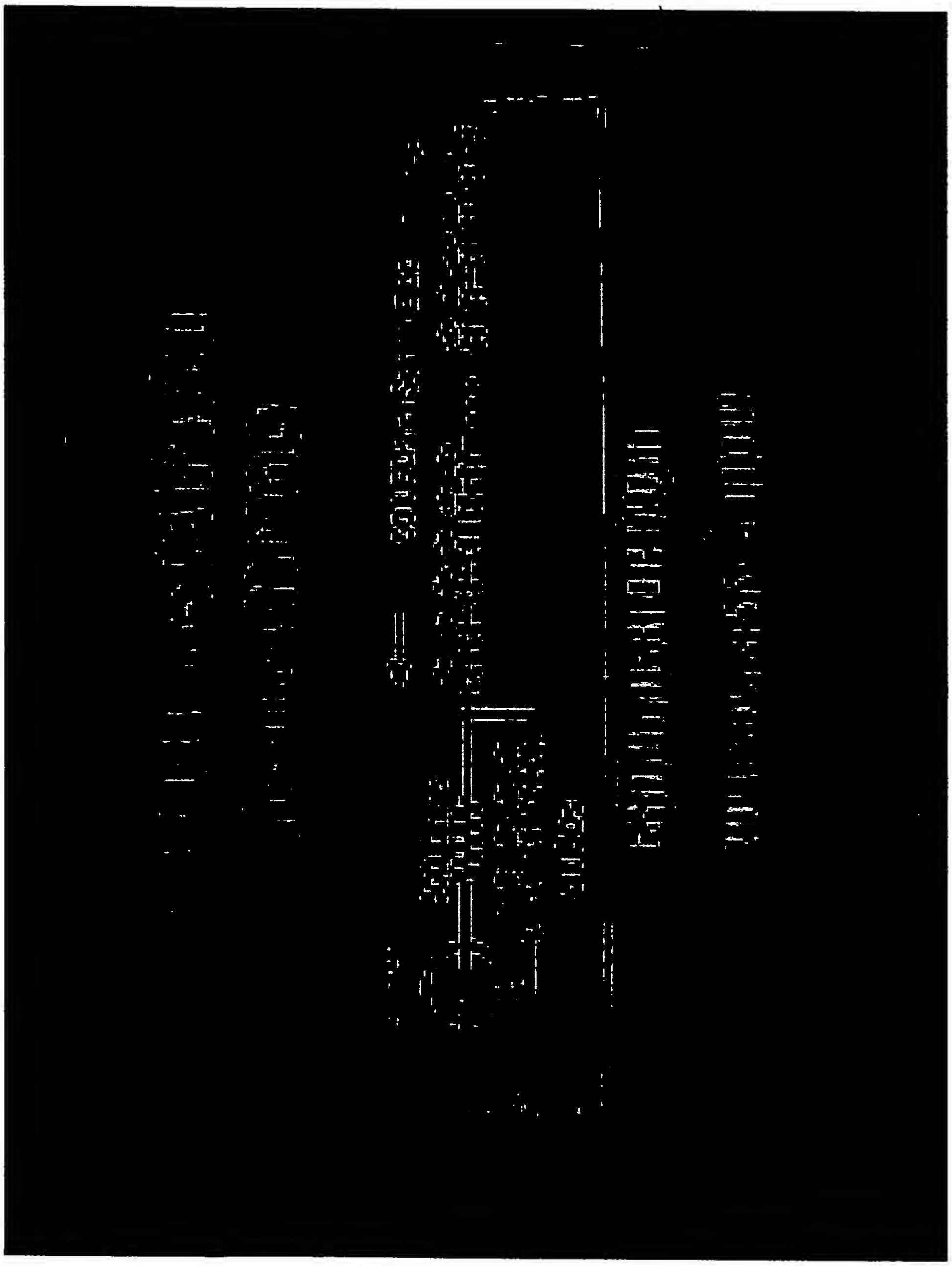
Note: It is known that LED voltage is specified under DC operating conditions.



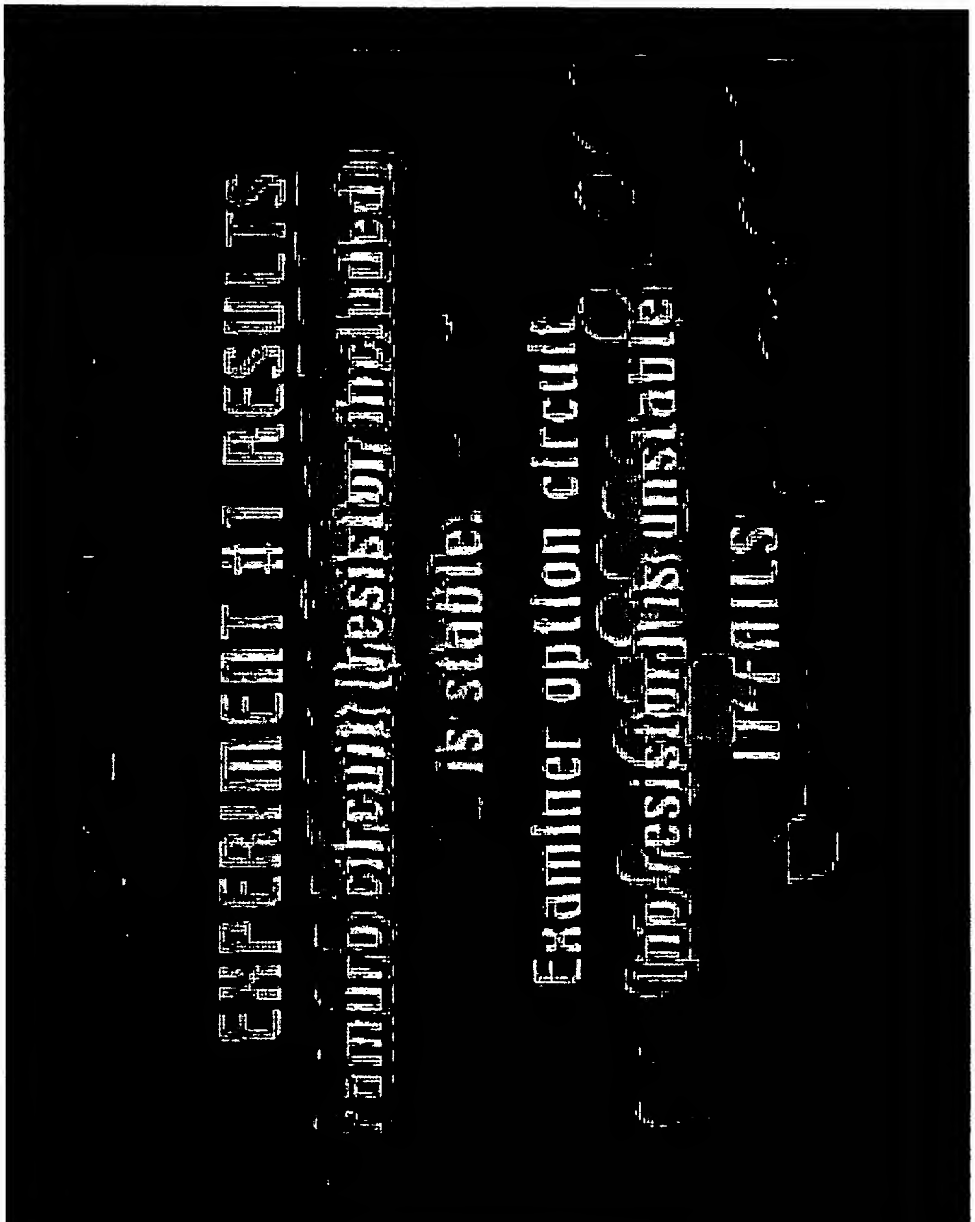
PHDATA:852544

DR. MARK ALLEN, Ph.D., Chief Technical Officer, Fiber Optics Designs, Inc.

One can see that this circuit works just fine. There's current that runs through... here's the five extra LEDs for the other circuit...here on this branch is the resistor that's being used. This is as 500 ohm resistor. It's actually very hot right now. That's one of the reasons why one would want to omit this resistor is that it generates heat.



The second case is the examiner's option where five LEDs are being substituted for the resistor, so let's count them: one, two, three, four, five are being substituted for this resistor. By means of a switch we toggle...and the circuit fails immediately.



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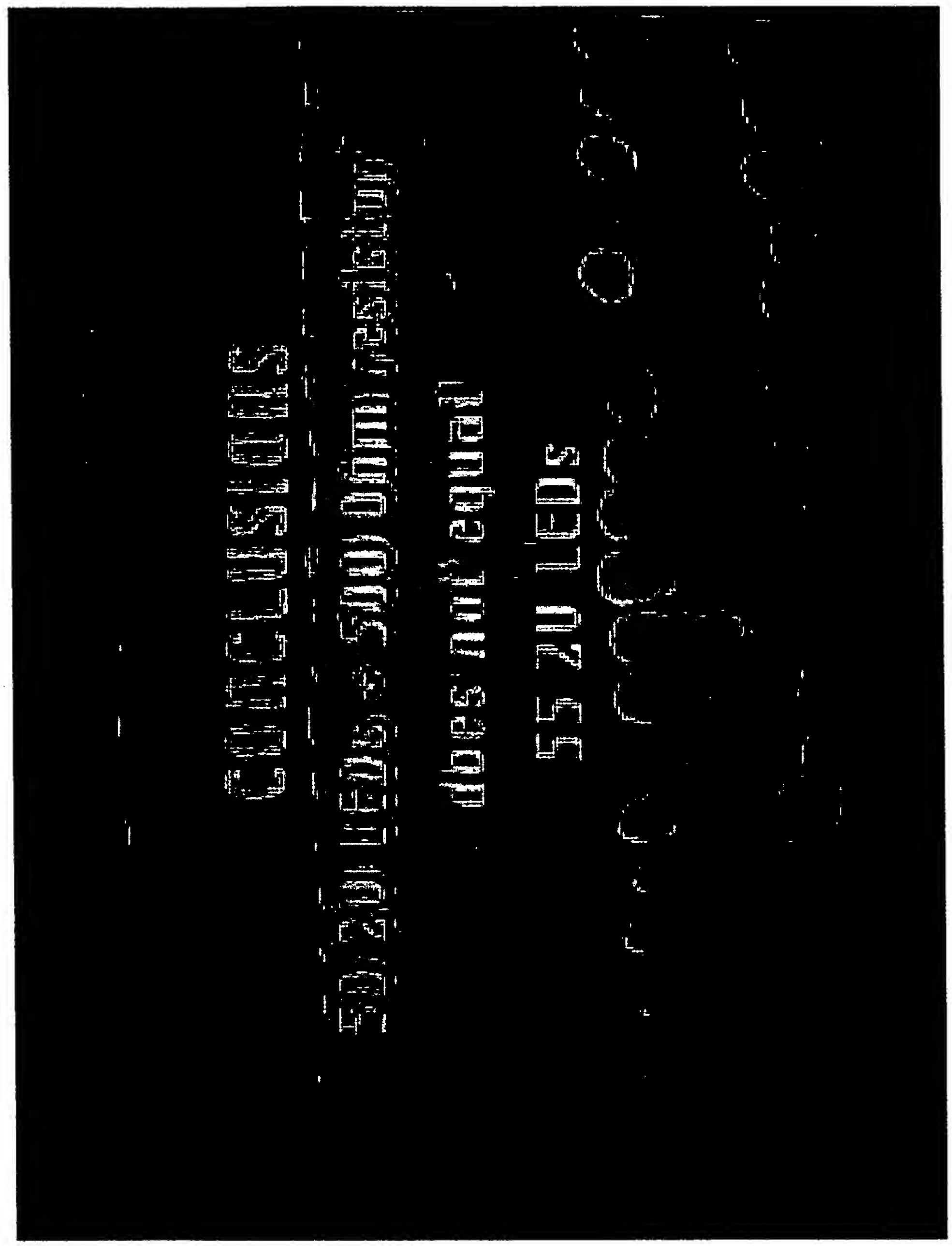
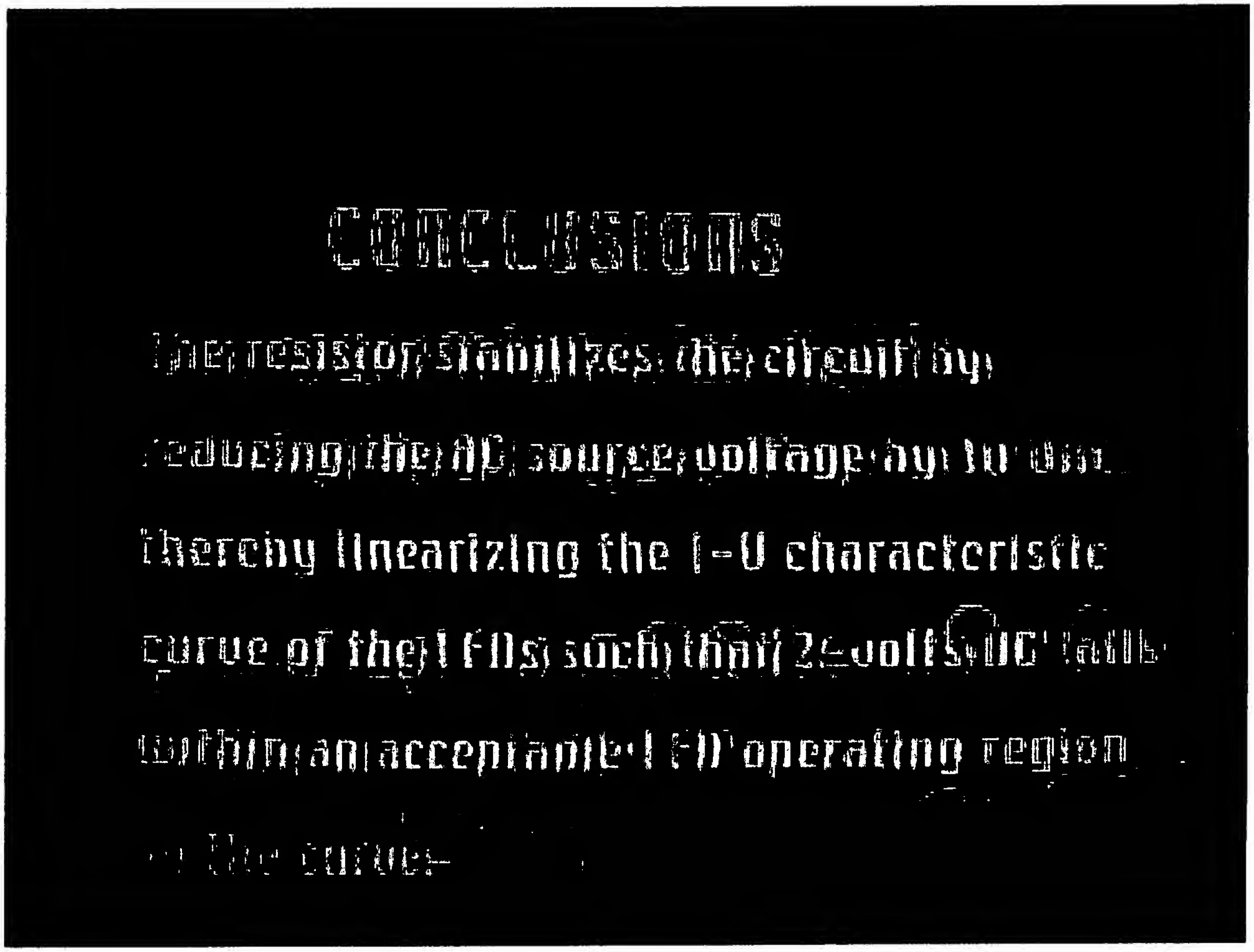

CONCLUSIONS
30 ZU LEDs + 500 Ohm resistor
does not equal
55 ZU LEDs



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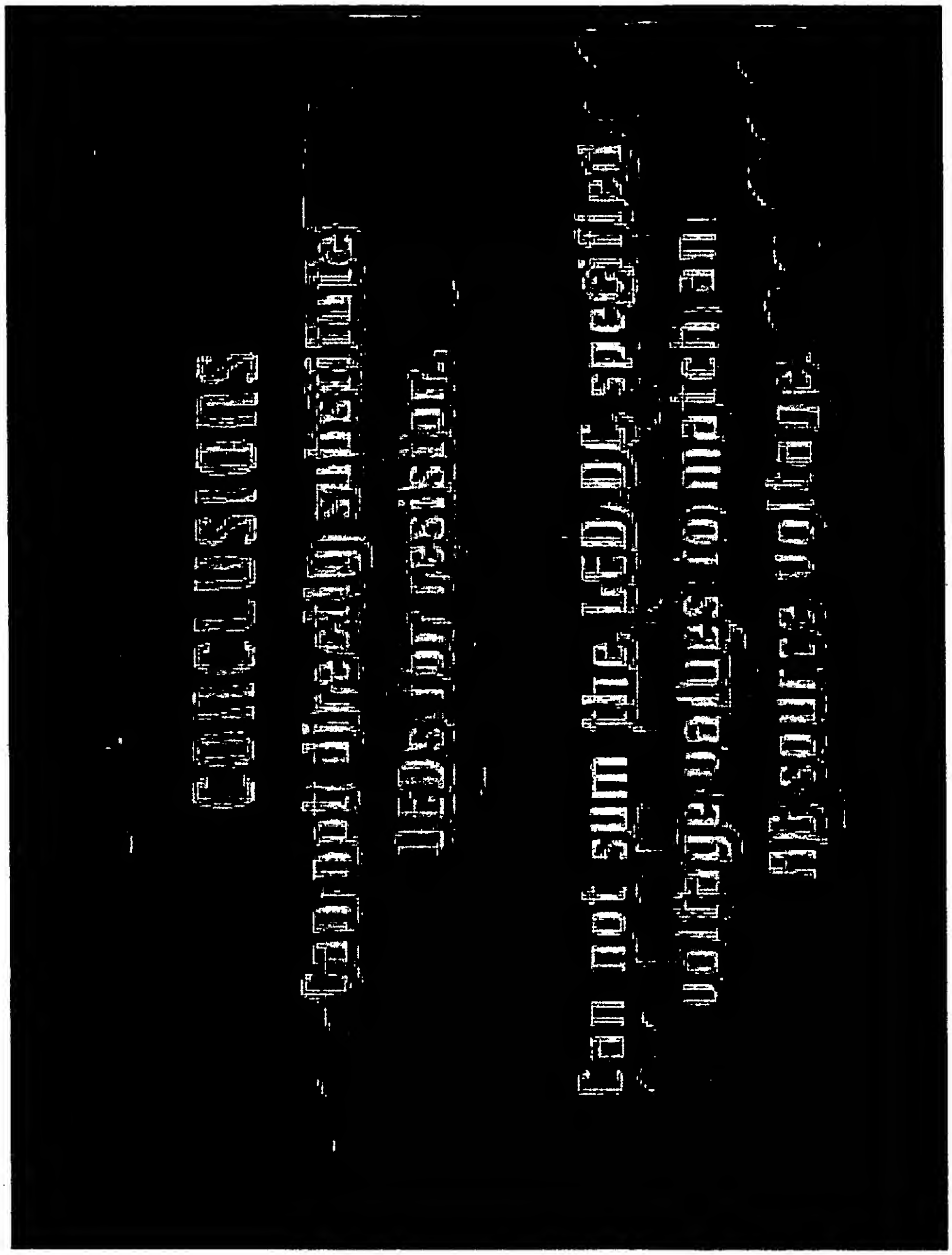

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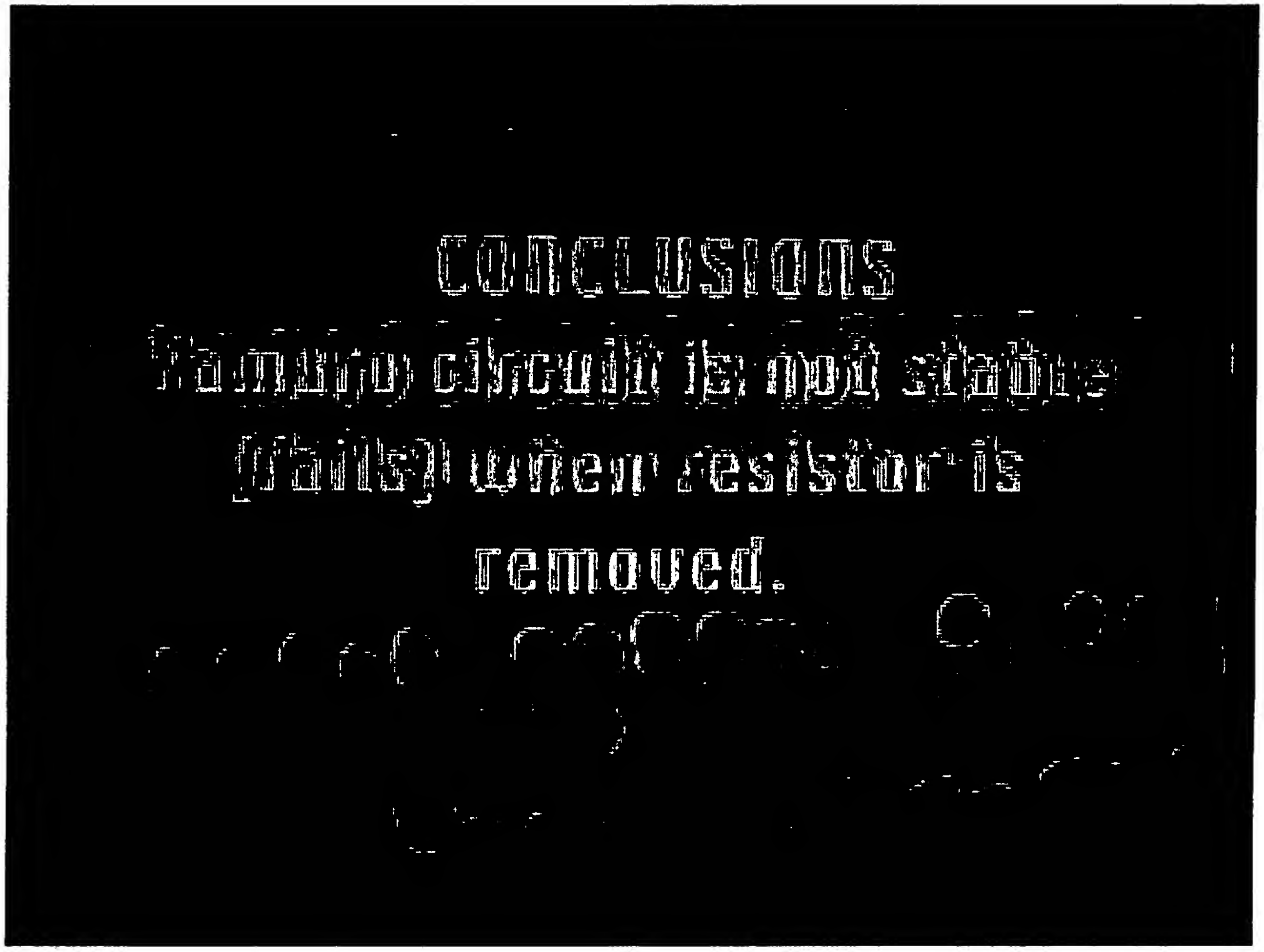
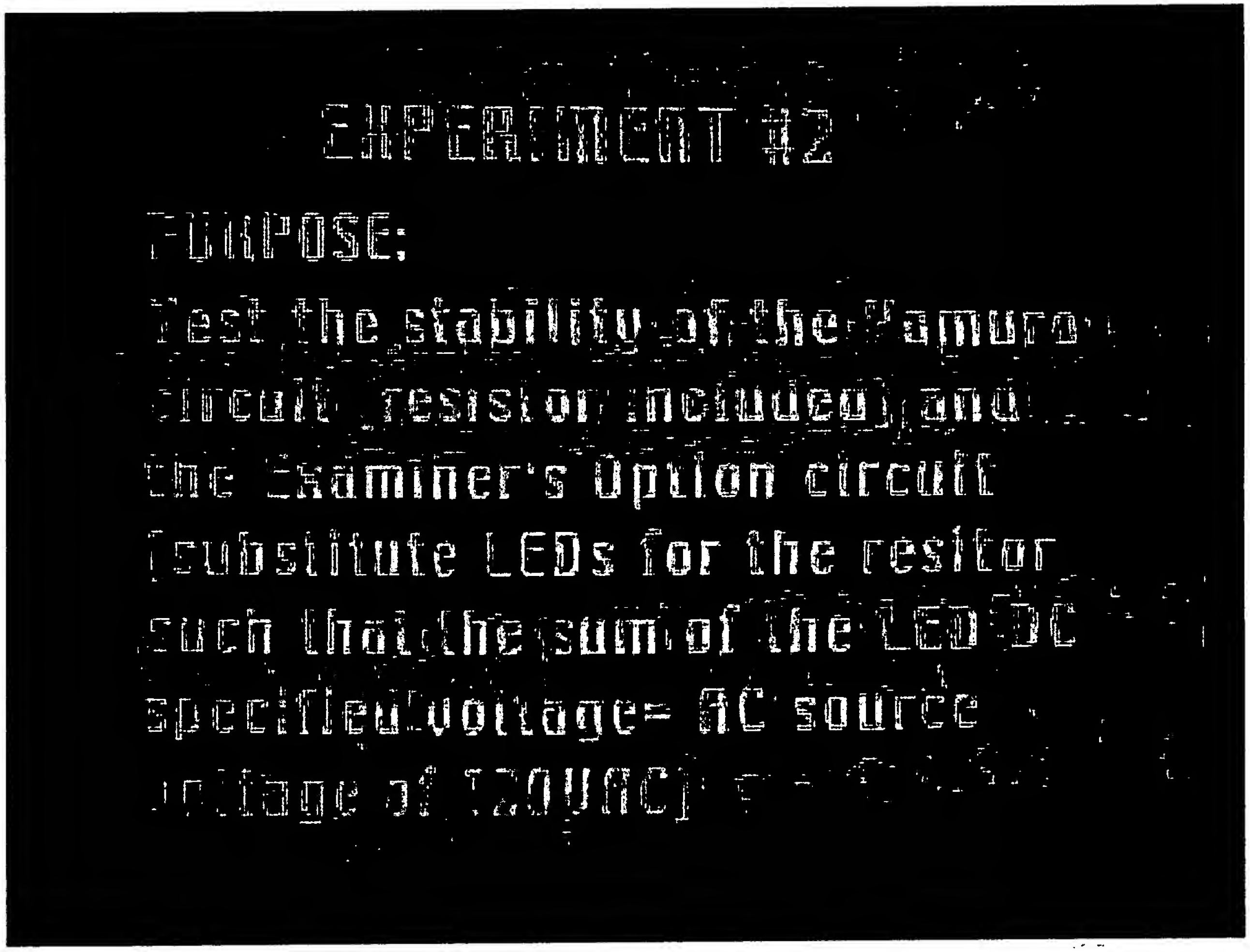

CONCLUSIONS
Tamuro circuit is not stable
(fails) when resistor is
removed.



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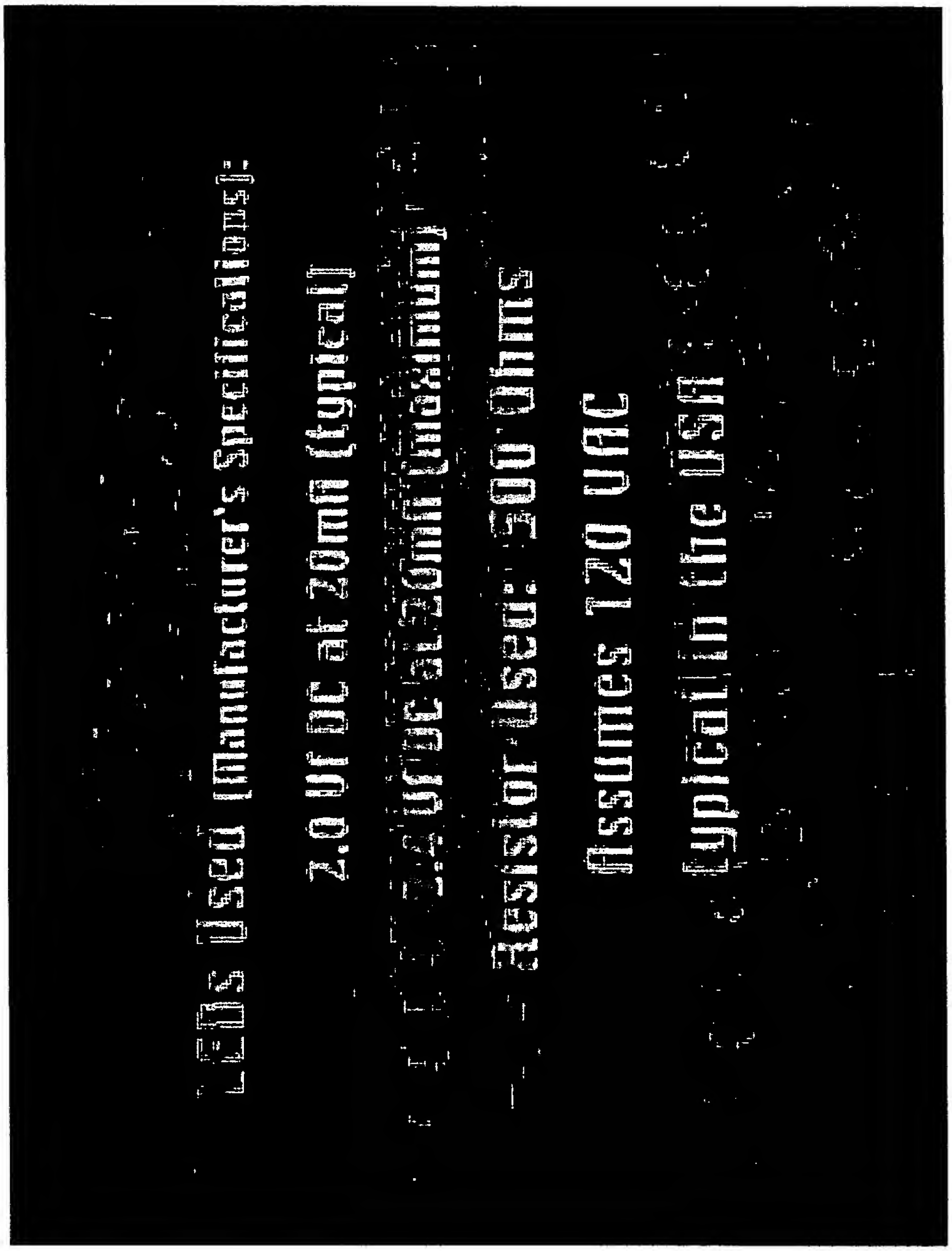
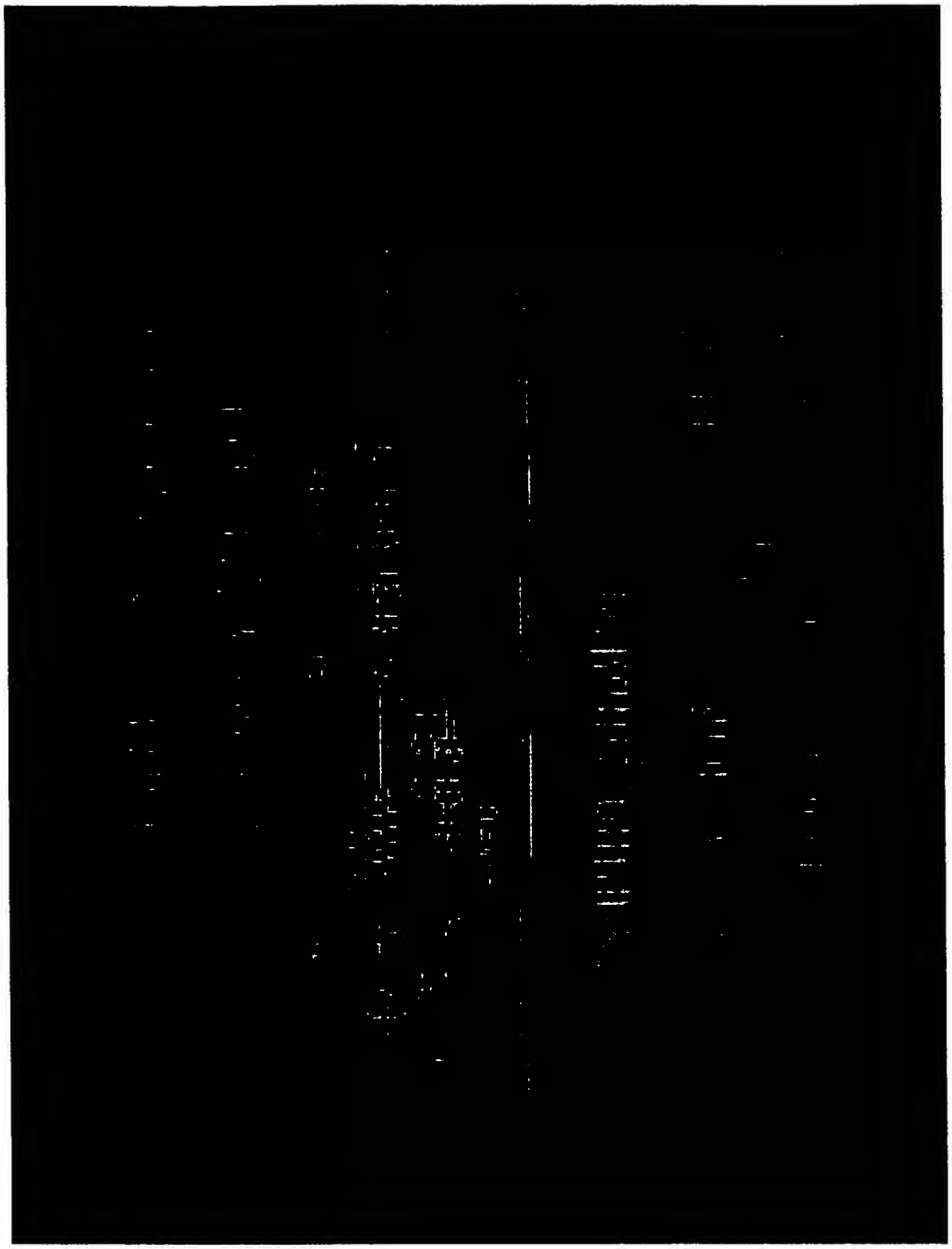
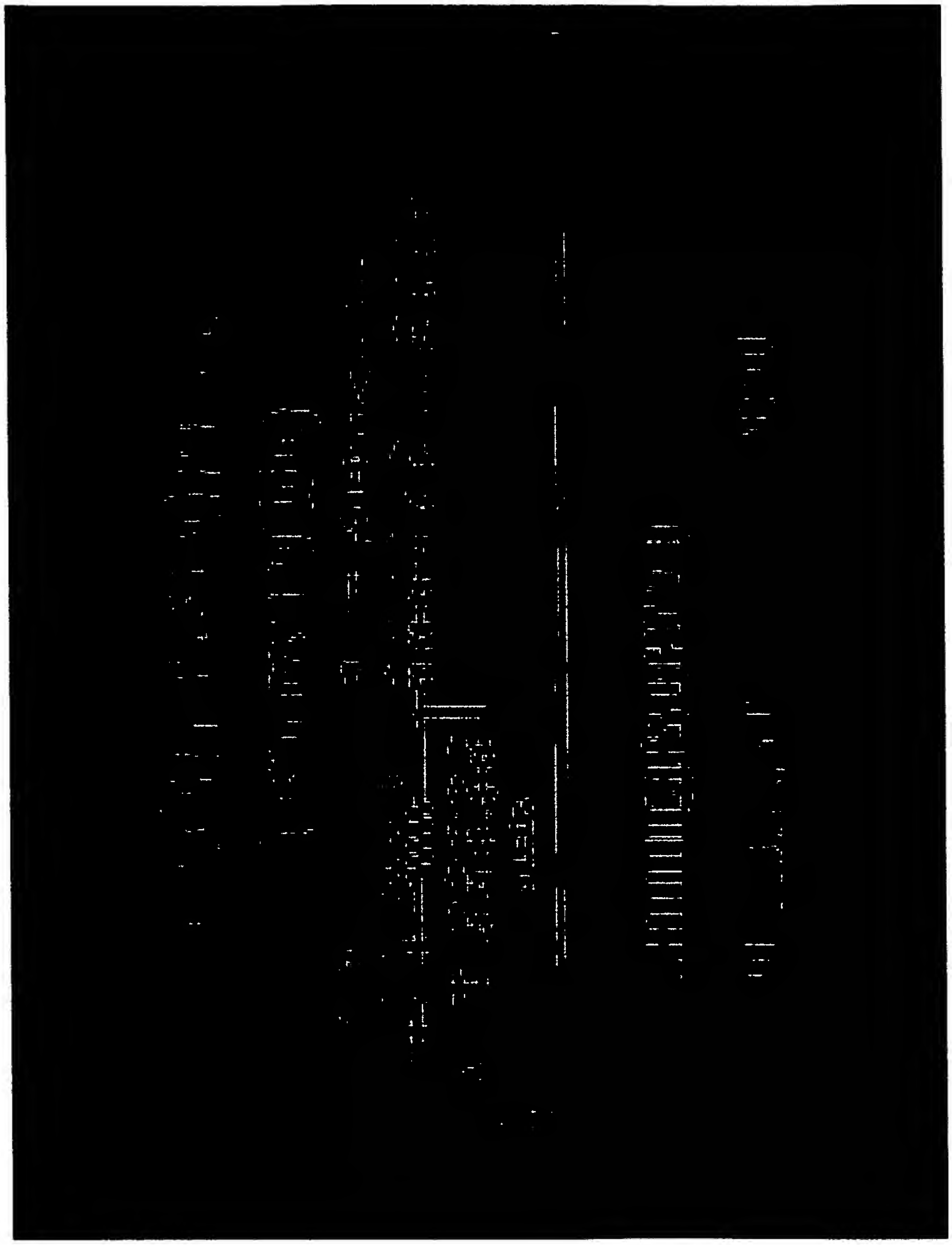
METHOD:

Duplicate the Yamuro circuit by building an equivalent circuit using U.S. AC source voltage...Experimental Circuit is identical to Yamuro's circuit since 55 20VDC LEDs + 500 Ohm resistor @ 120 VAC (experiment) = 45 20VDC LEDs + 500 Ohm resistor @ 100VAC (Yamuro Example).


LEDs Used (Manufacturer's Specifications):
2.0 Vf DC at 20mA (typical)
2.4 Vf DC at 20mA (maximum)
Resistor Used: 500 Ohms
Assumes 120 VAC
Typical in the USA



So I have the toggle set...switch...set...to resistor...I plug it in. Notice that the circuit is working. Let's wait for awhile and notice further that the circuit works for some period of time.



When I do flick the switch to account for the examiner option, instead of the Yamuro circuit, we will be able to see that it will indeed fail. So, are you ready here camera man? I will flick the switch from the Yamuro circuit to the examiner's circuit. First we see that the circuit is being stressed. What's happening here is that the LEDs are over-voltaged again and they are starting to fail. We'll wait a few seconds. These things are hot! One just failed immediately. Here's another one that's failed...here's another one that's failed...the whole thing has finally failed. Once a few fail it's an avalanche process because there are less and less LEDs to take up the voltage in the circuit.

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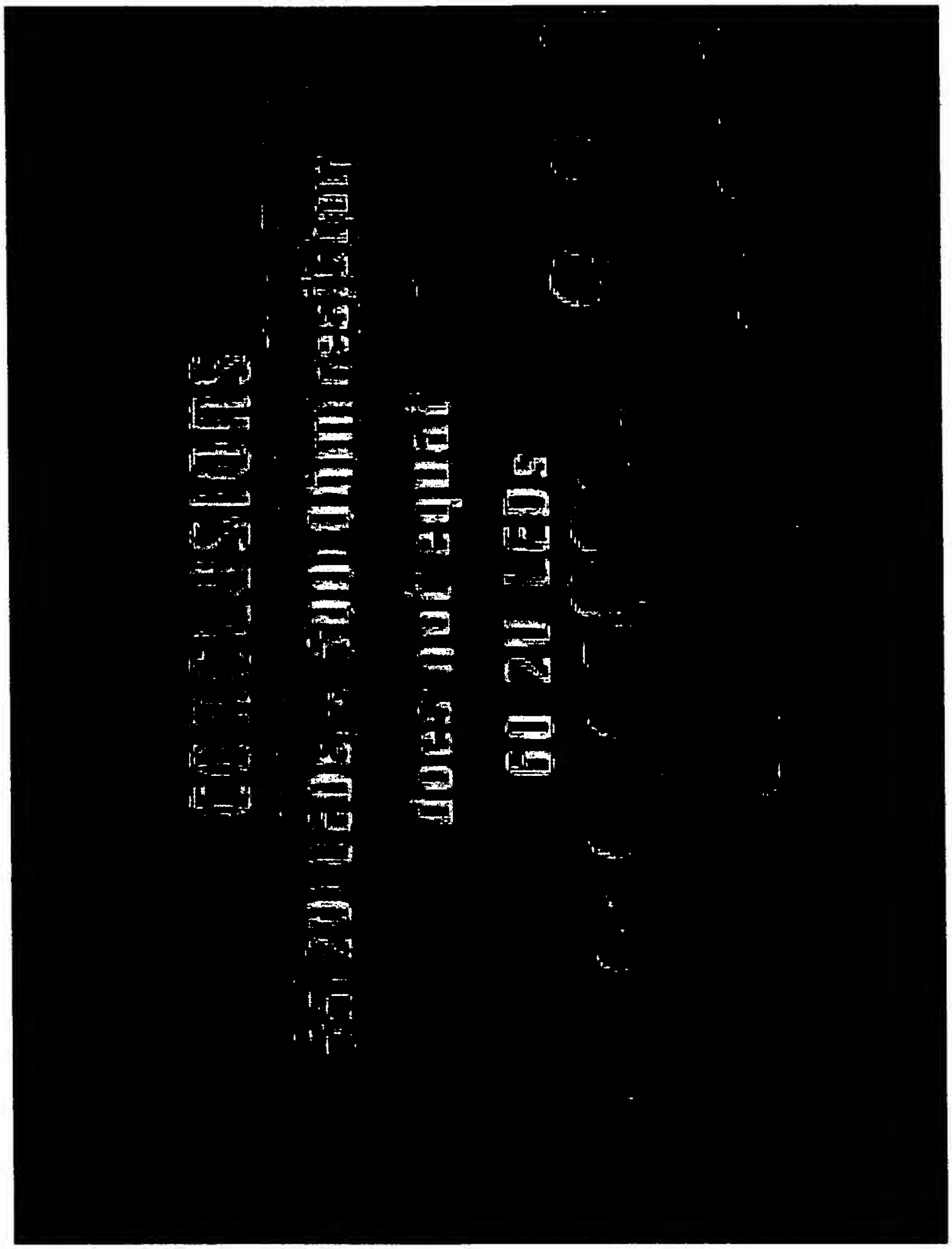
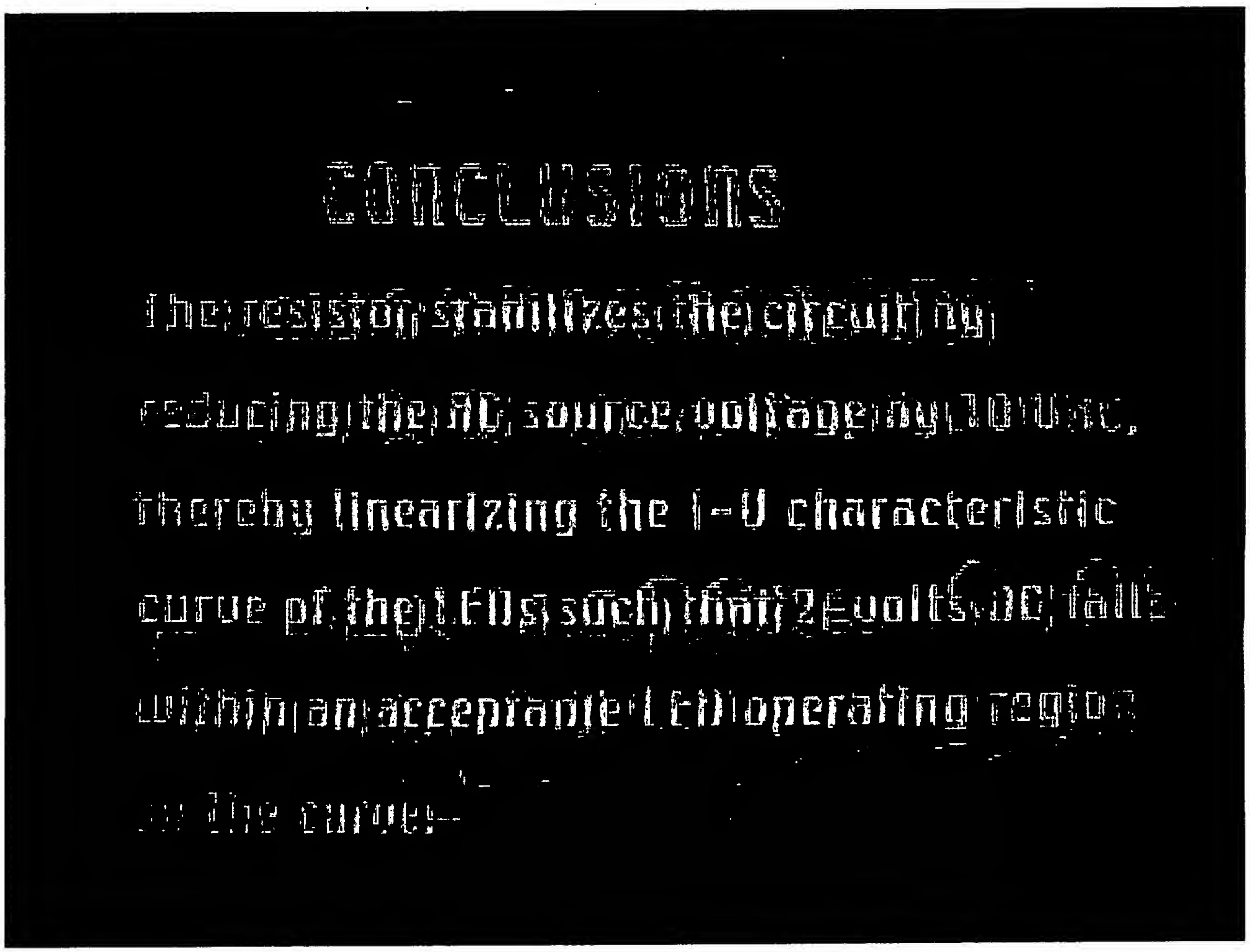
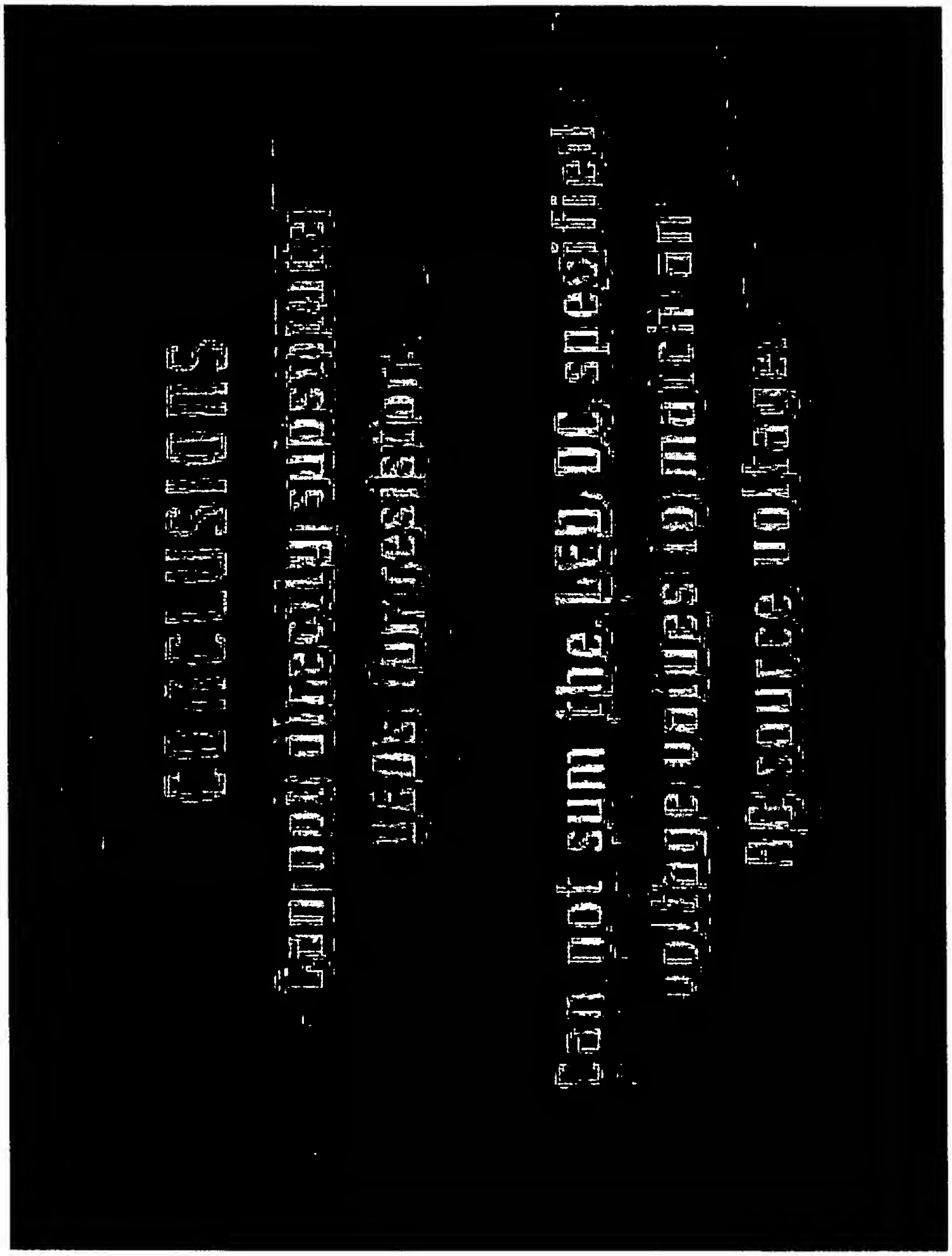

CONCLUSIONS
does not equal
60 20 LEDs


CONCLUSIONS
The resistor stabilizes the circuit by
reducing the AC source voltage by 10 VAC,
thereby linearizing the I-V characteristic
curve of the LEDs such that 2 volts DC falls
within an acceptable LED operating region
of the curve.



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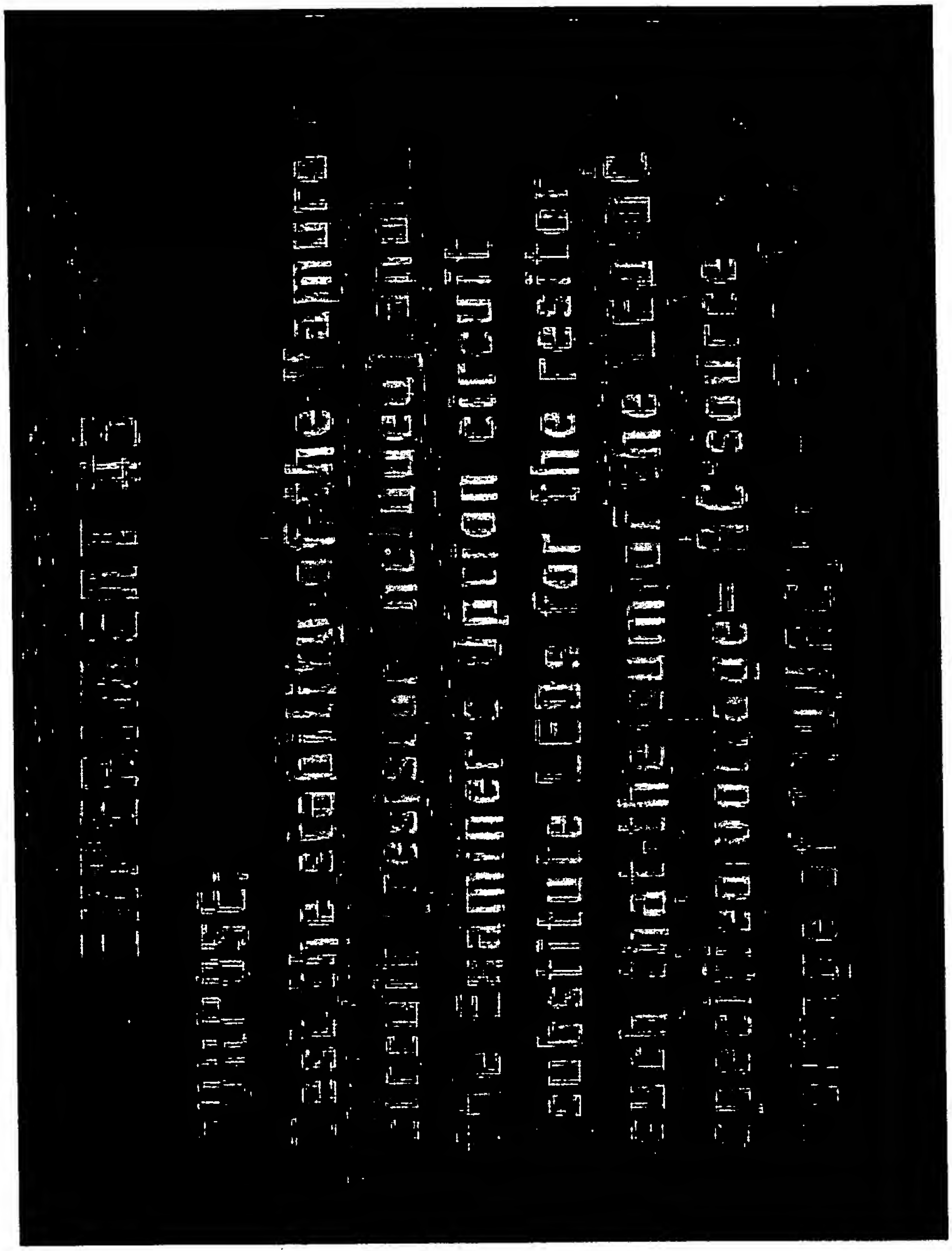
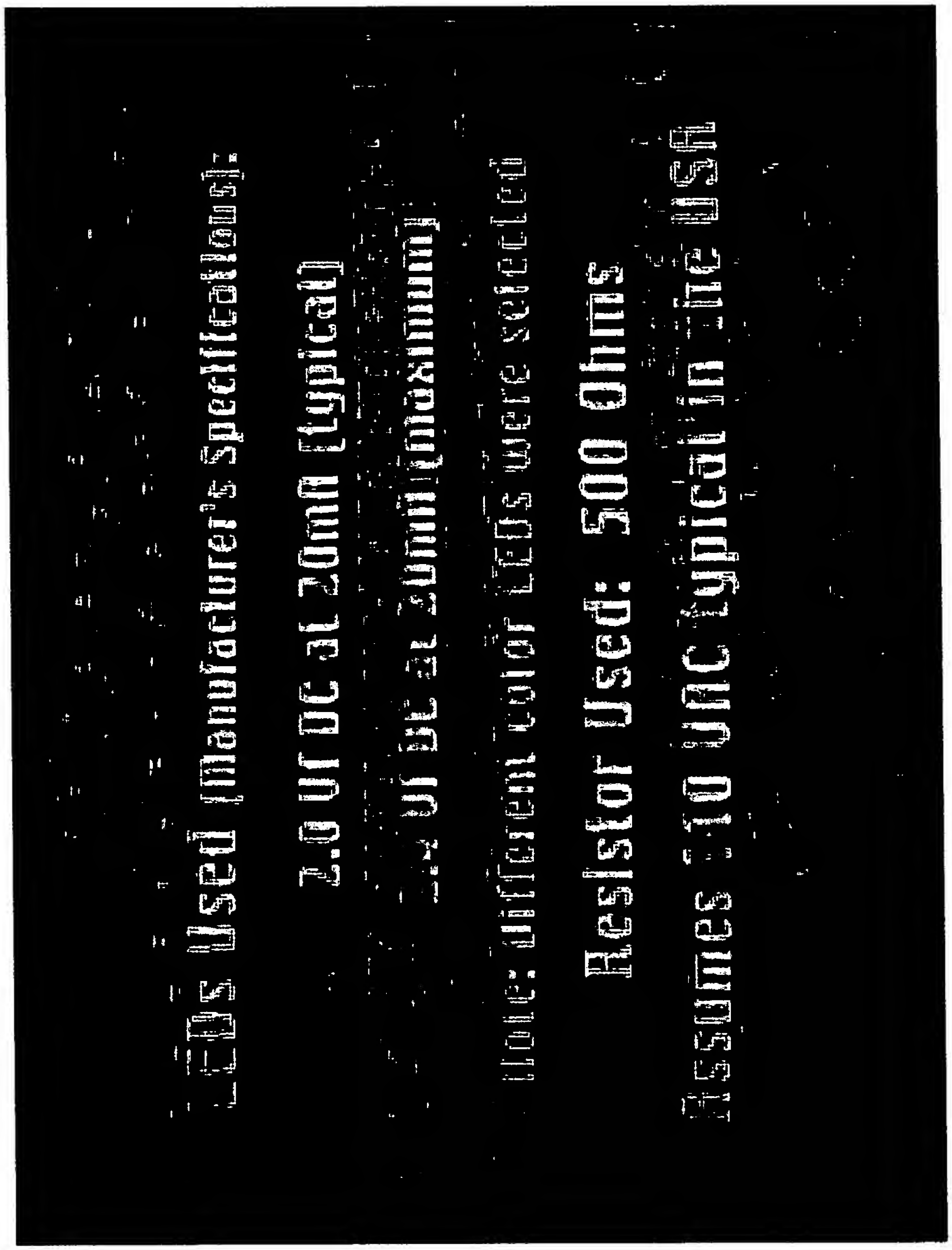
CONCLUSIONS

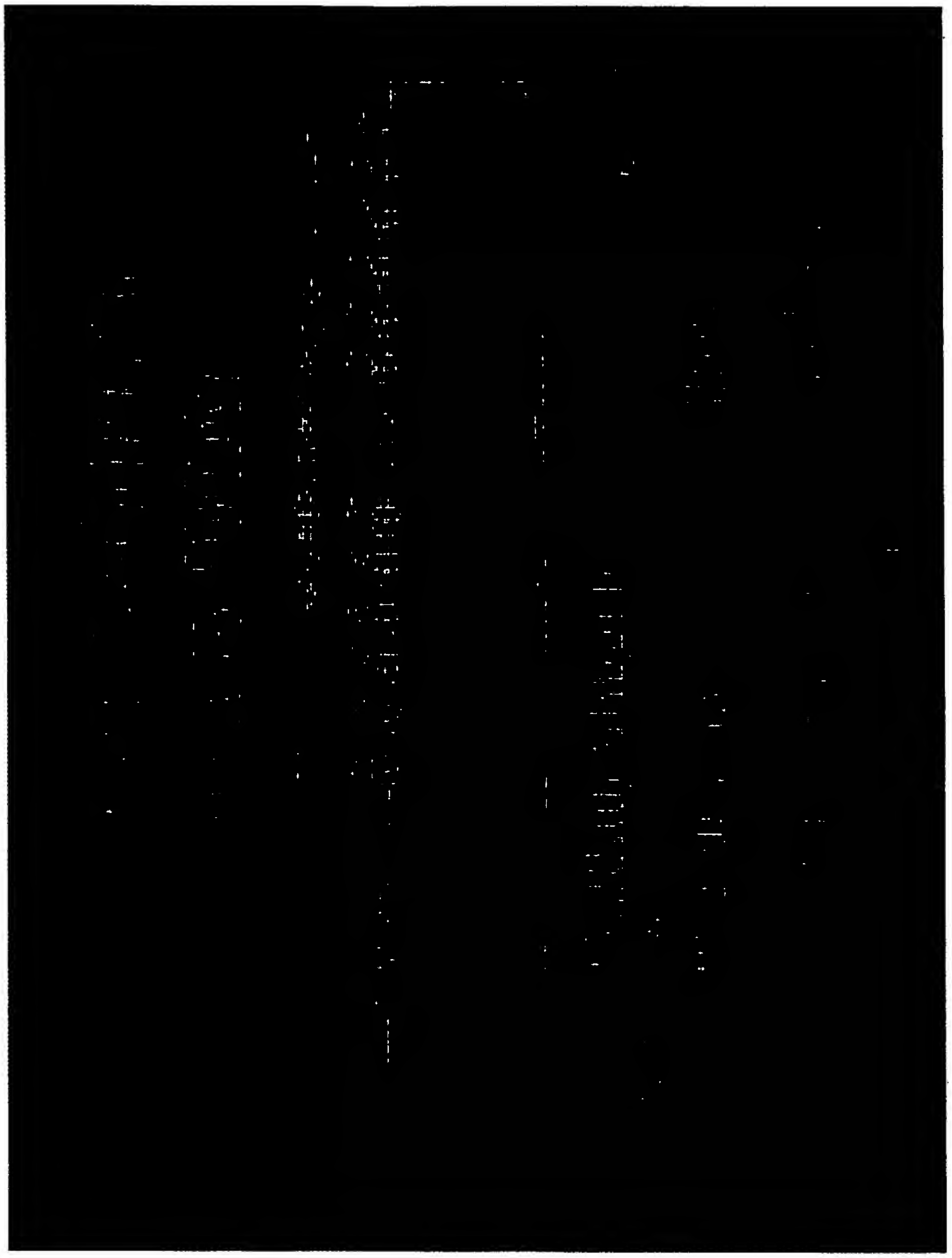
Timing circuit is not stable (fails) when resistor is removed.


EXPERIMENT
PURPOSE:
the stability of the
resistor
Examiner's option circuit
substitute LEDs for the resitor
such that the sum of the
specified voltage= AC source

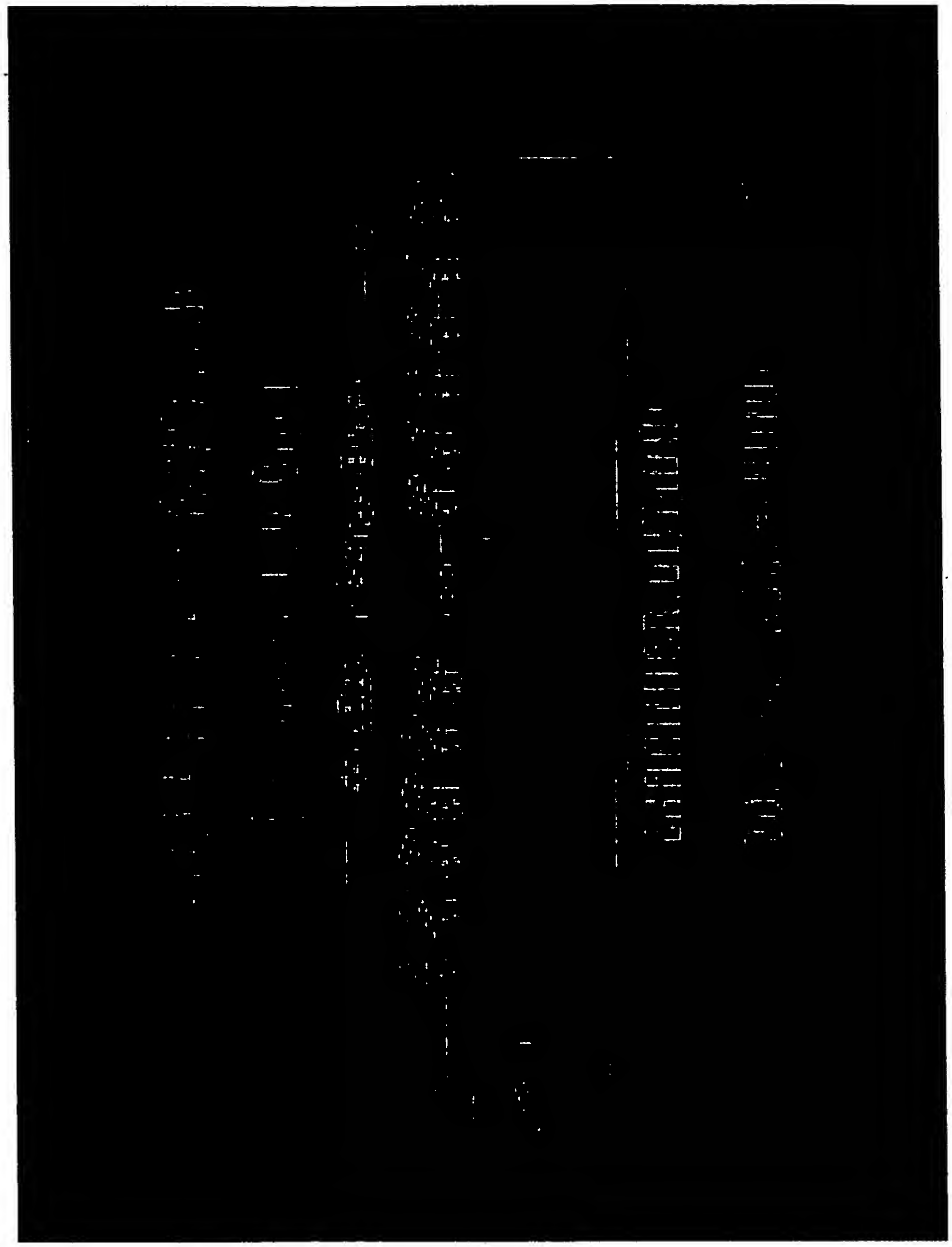
METHOD:

Duplicate the Yamuro circuit by building an equivalent circuit using U.S. AC source voltage...Experimental Circuit is identical to Yamuro's circuit since 55 2VDC LEDs + 500 Ohm resistor @ 110-120VAC (experiment) = 45 2VDC LEDs + 500 Ohm resistor @ 100VAC (Yamuro Example).

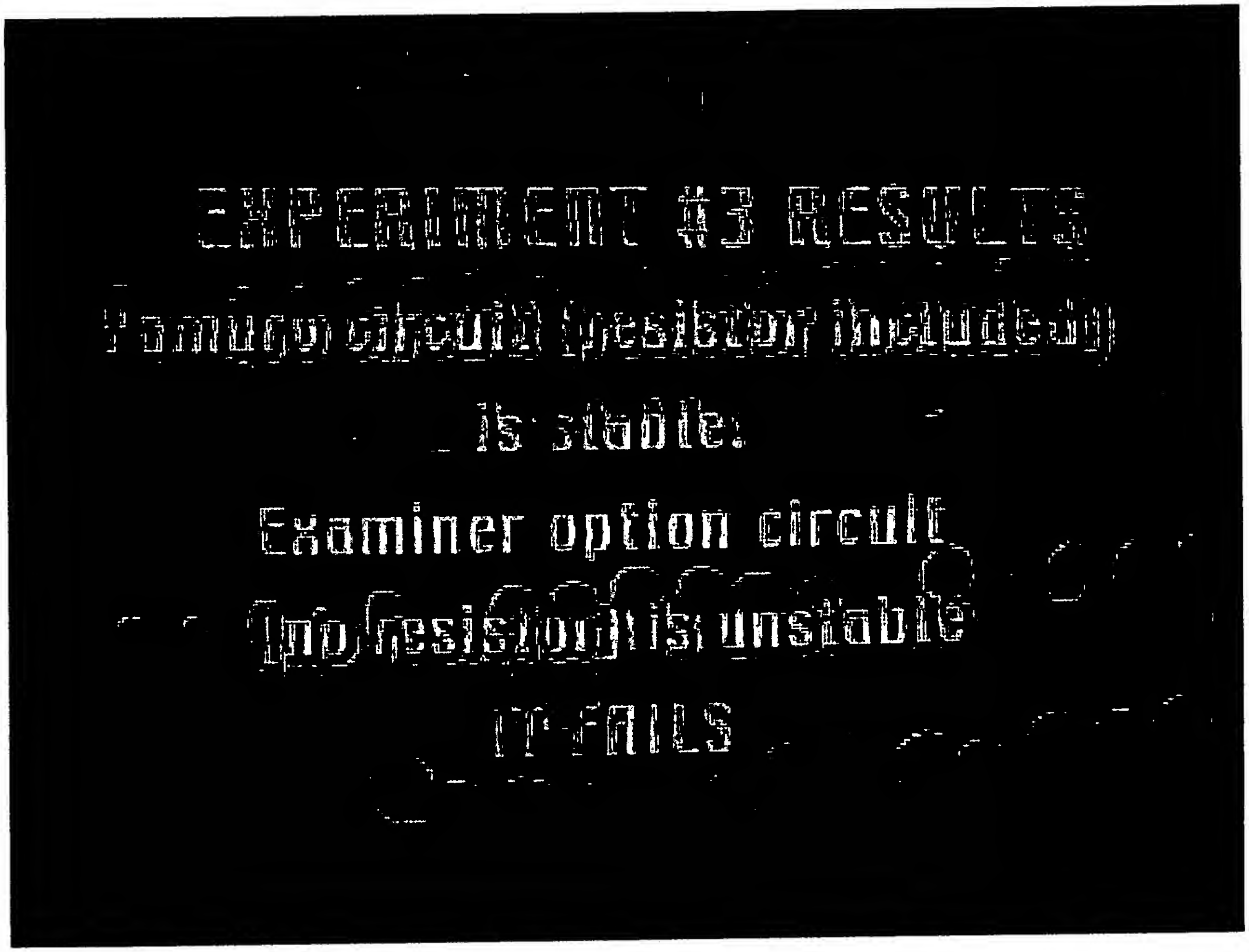

LEDs Used (Manufacturer's Specifications):
2.0 Vf DC at 20mA (typical)
Vf DC at 20mA (maximum)
Note: different color LEDs were selected
Resistor Used: 500 Ohms
Assumes 110 VAC typical in the USA



I have a resistor on here that's 500 Ohms as before. That's what we just demonstrated. I can plug this circuit in, and show that this circuit, which is the same as Yamuro's, works just fine. Notice that the brightness is approximately the same [as our circuit, edited out] and this resistor is getting very hot actually.



Now, as an alternative to this, one can take the resistor out and join these wires together. Now remember that there are 55 LEDs in this circuit. Have the attorney verify this. I'll join these two wires so this is the same as that 110 volt case for the examiner. The examiner's option where there is no resistor used. I'll plug it in and...it failed. Rather quickly in fact. I wouldn't want to sell this to somebody.


EXPERIMENT #3 RESULTS
circuit (resistor included)
is stable.
Examiner option circuit
(no resistor) is unstable
IT FAILS

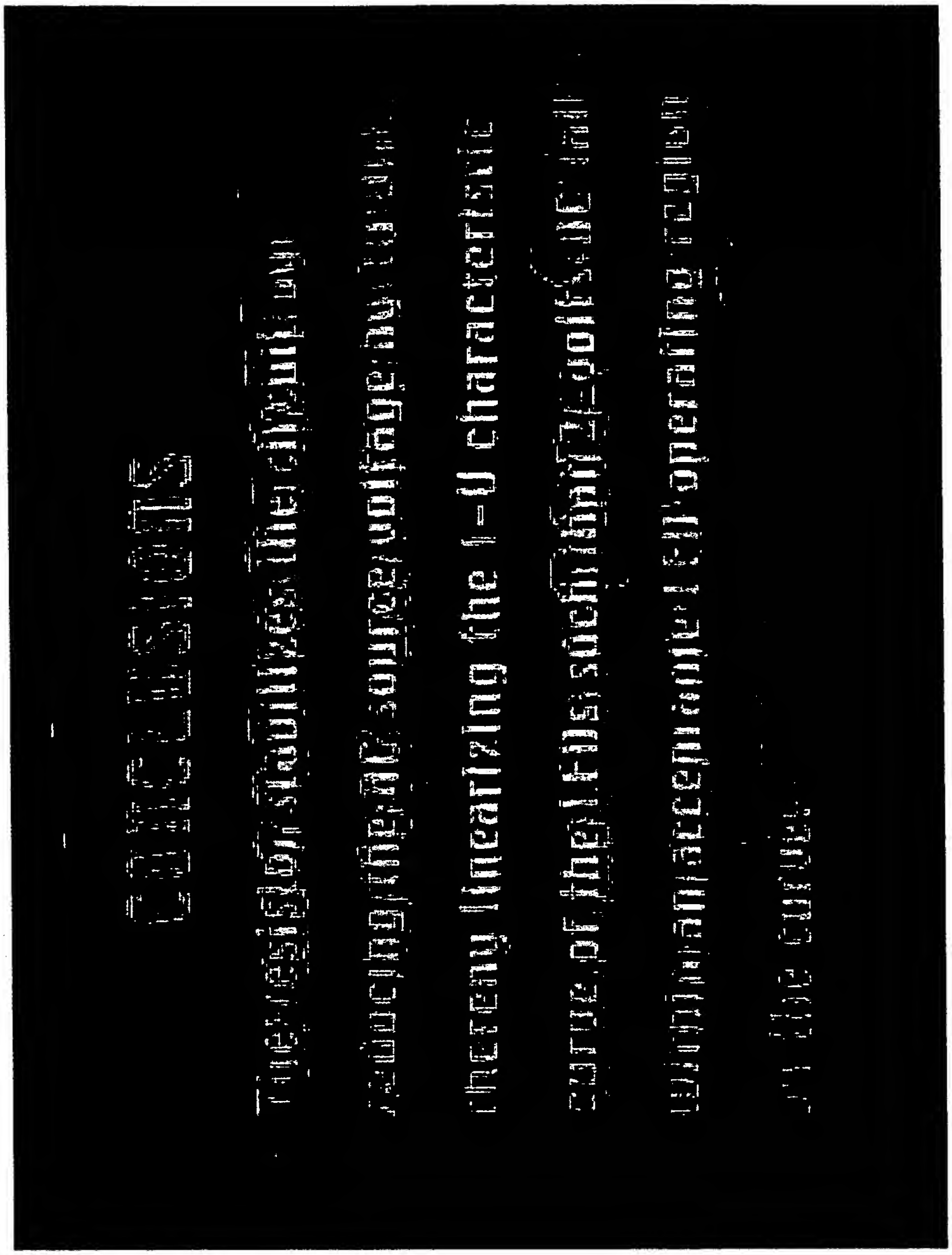
CONCLUSIONS

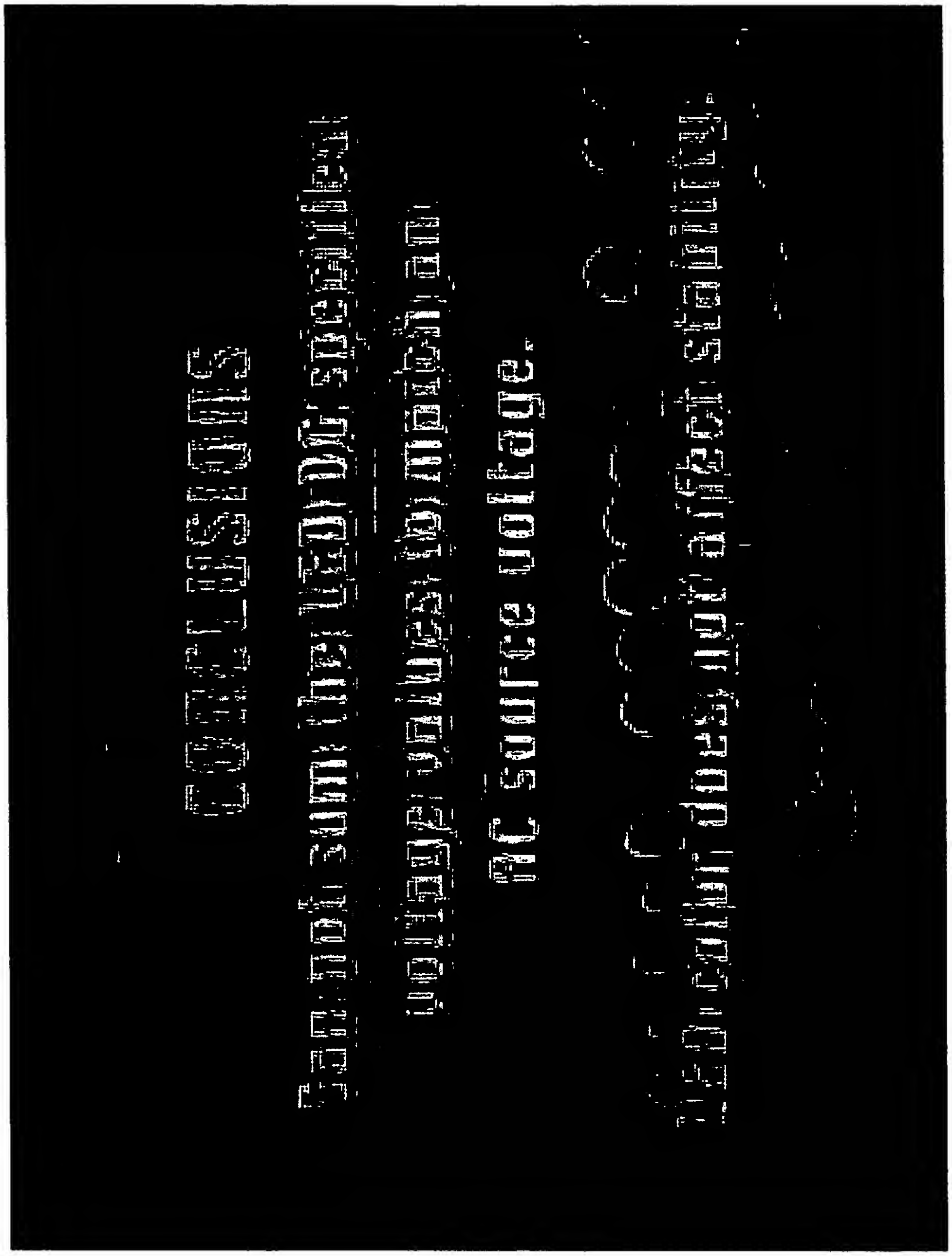
55 2V LEDs + 500 Ohm resistor

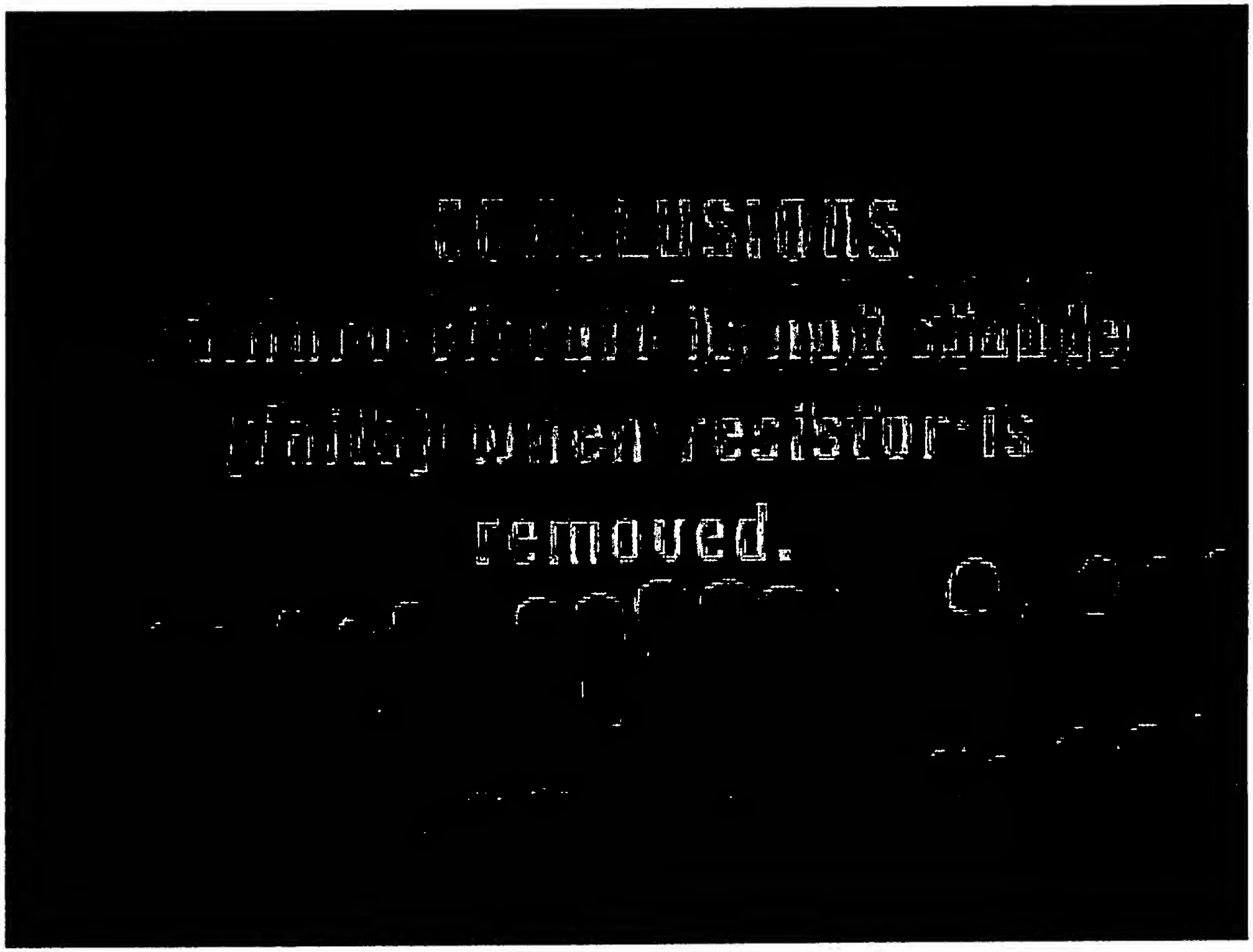
@ 120 VAC

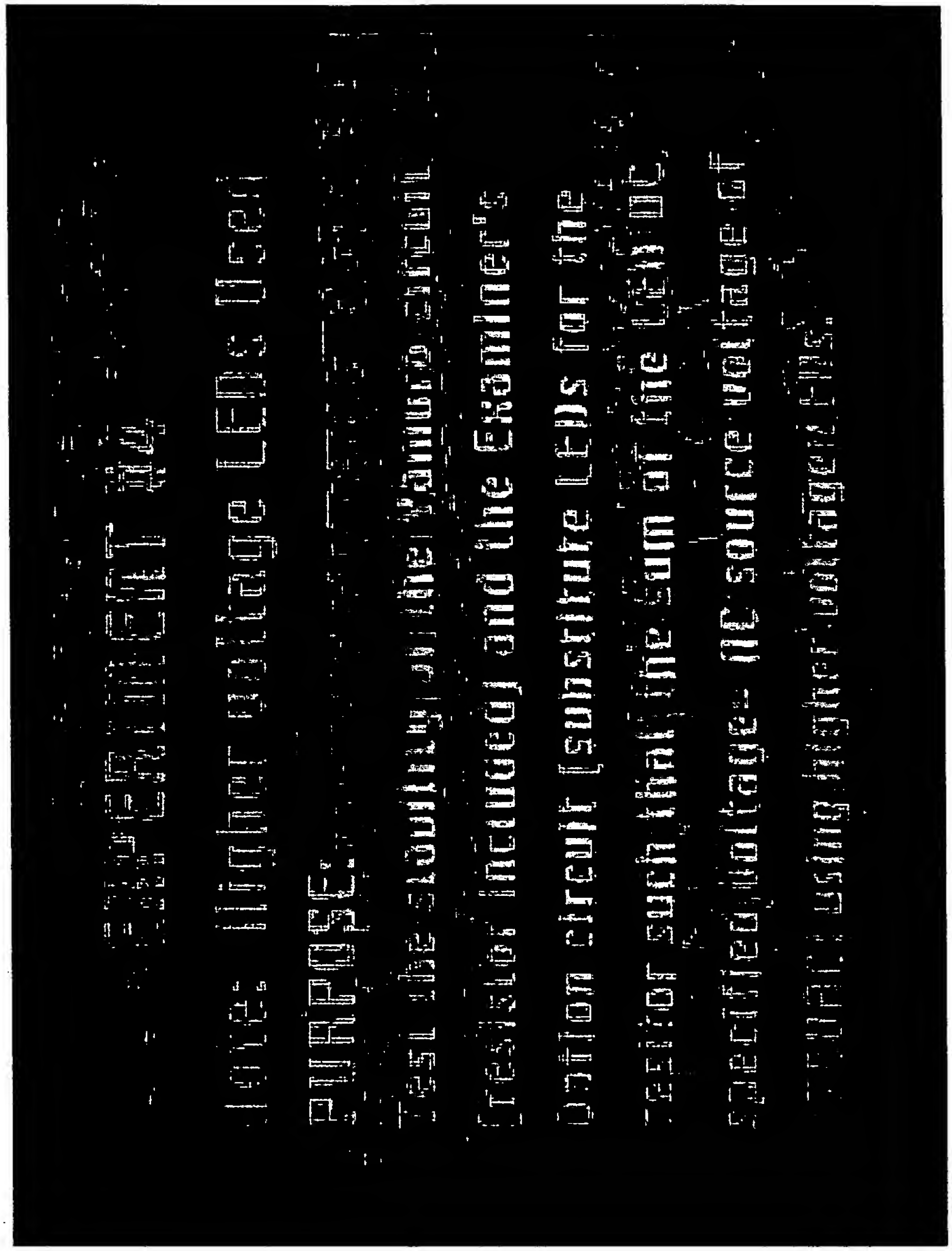
does not equal

55 2V LEDs @ 110 VAC


CONCLUSIONS
The resistor stabilizes the circuit by
reducing the AC source voltage by
thereby linearizing the I-V characteristic
curve of the LEDs such that
within an acceptable LED operating region
on the curve.


CONCLUSIONS
Can not sum the LED DC specified
voltage values to match an
AC source voltage.
LED color does not affect stability.

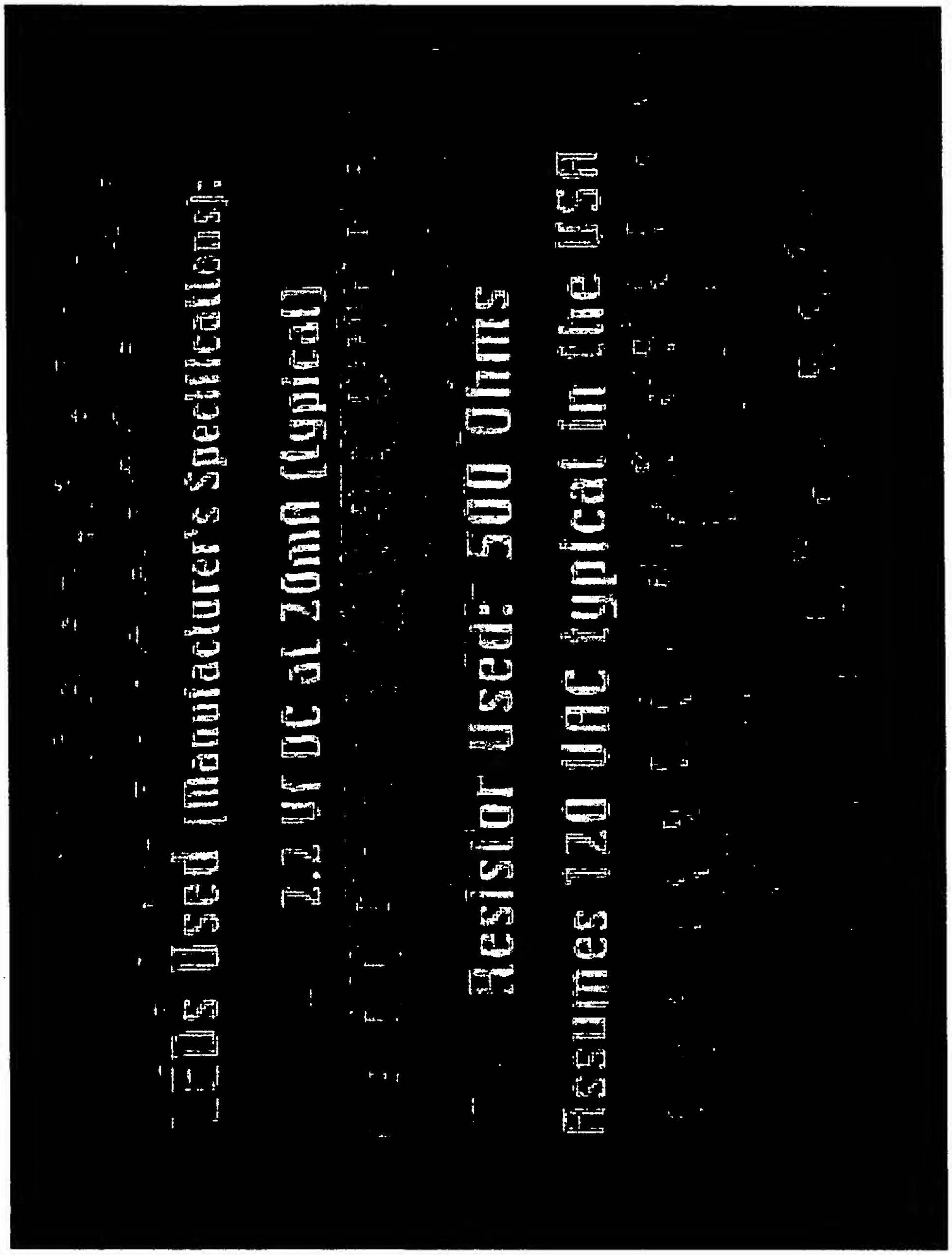

CONCLUSIONS
circuit is not stable
(fails) when resistor is
removed.

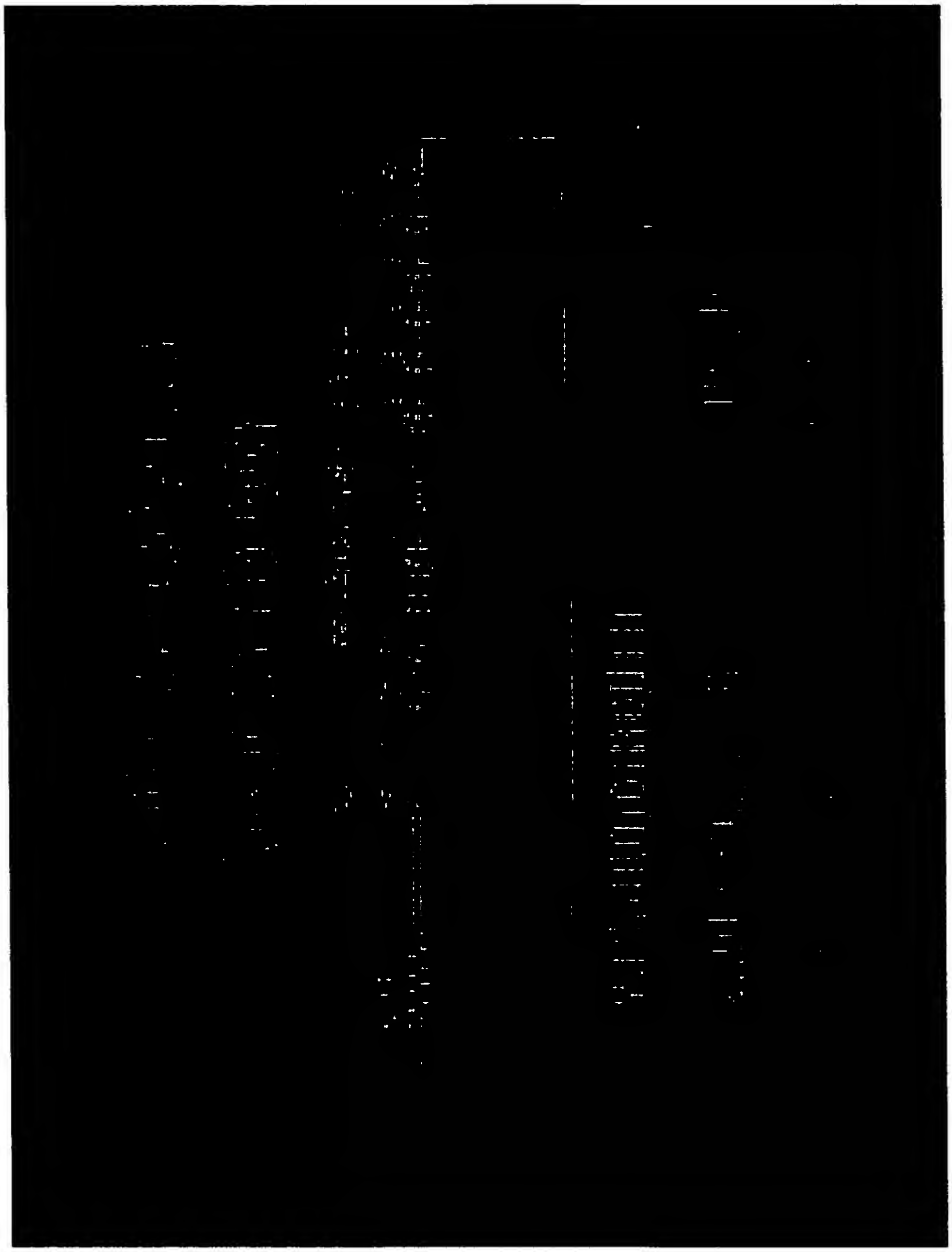


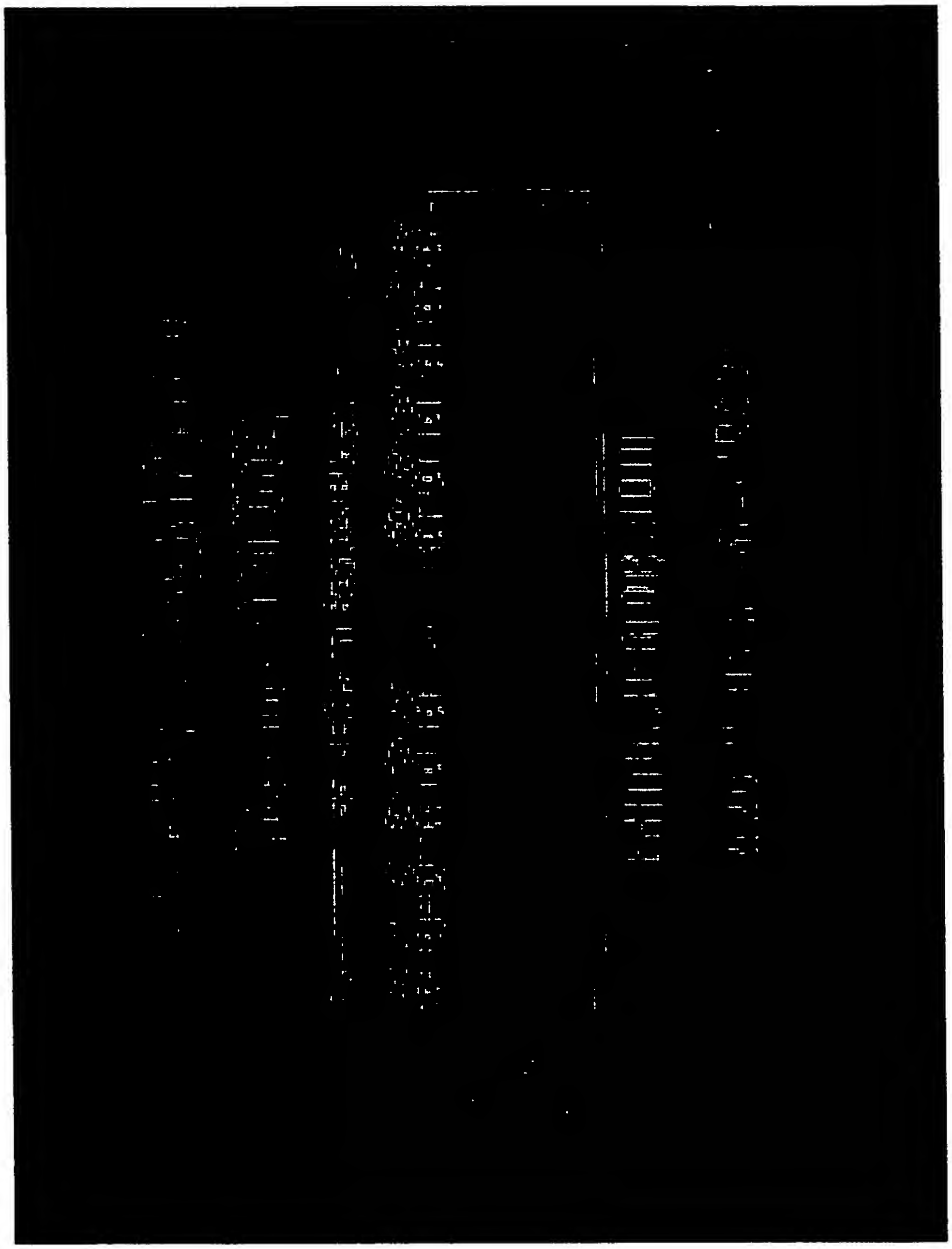
PHDATA:852544

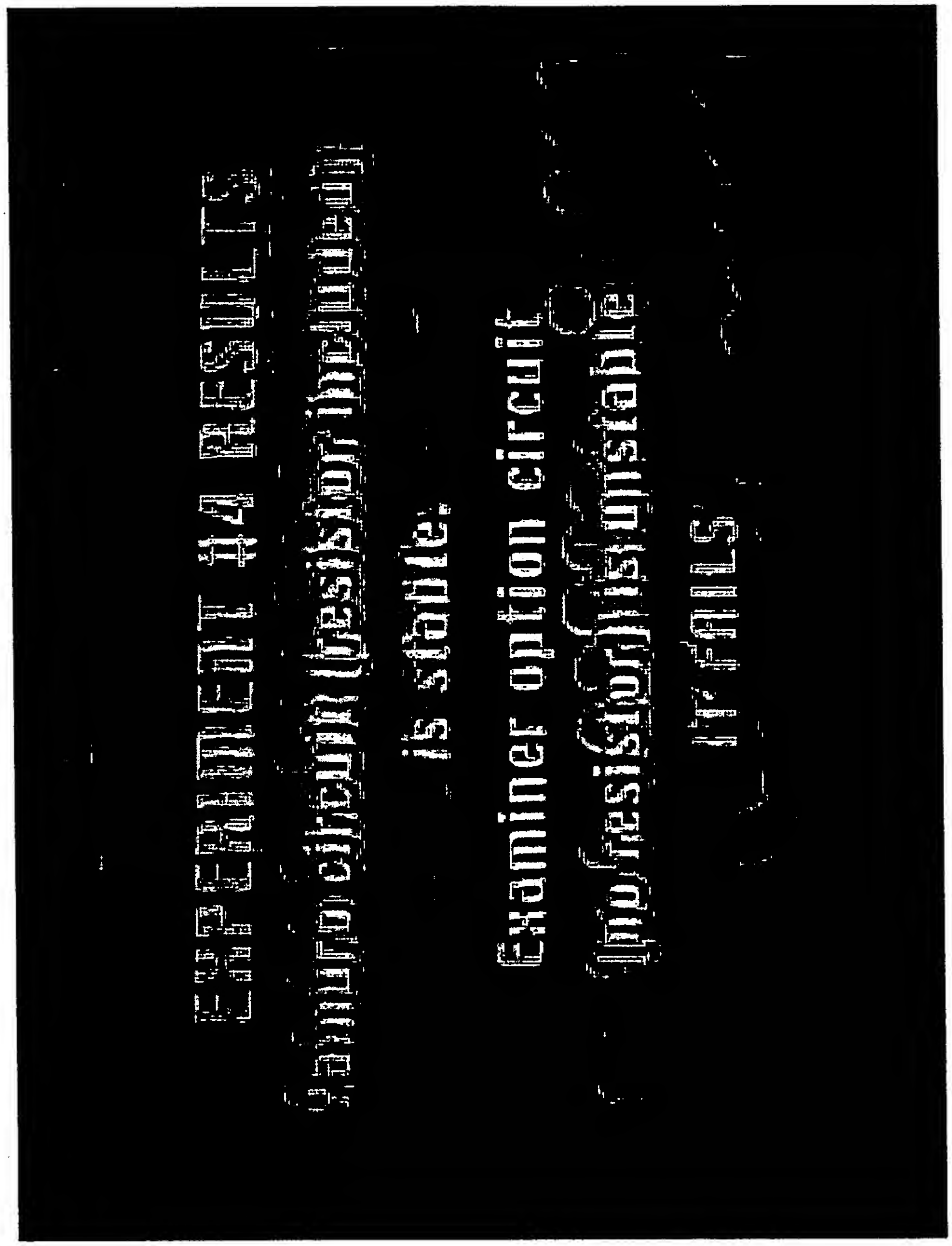
METHOD:

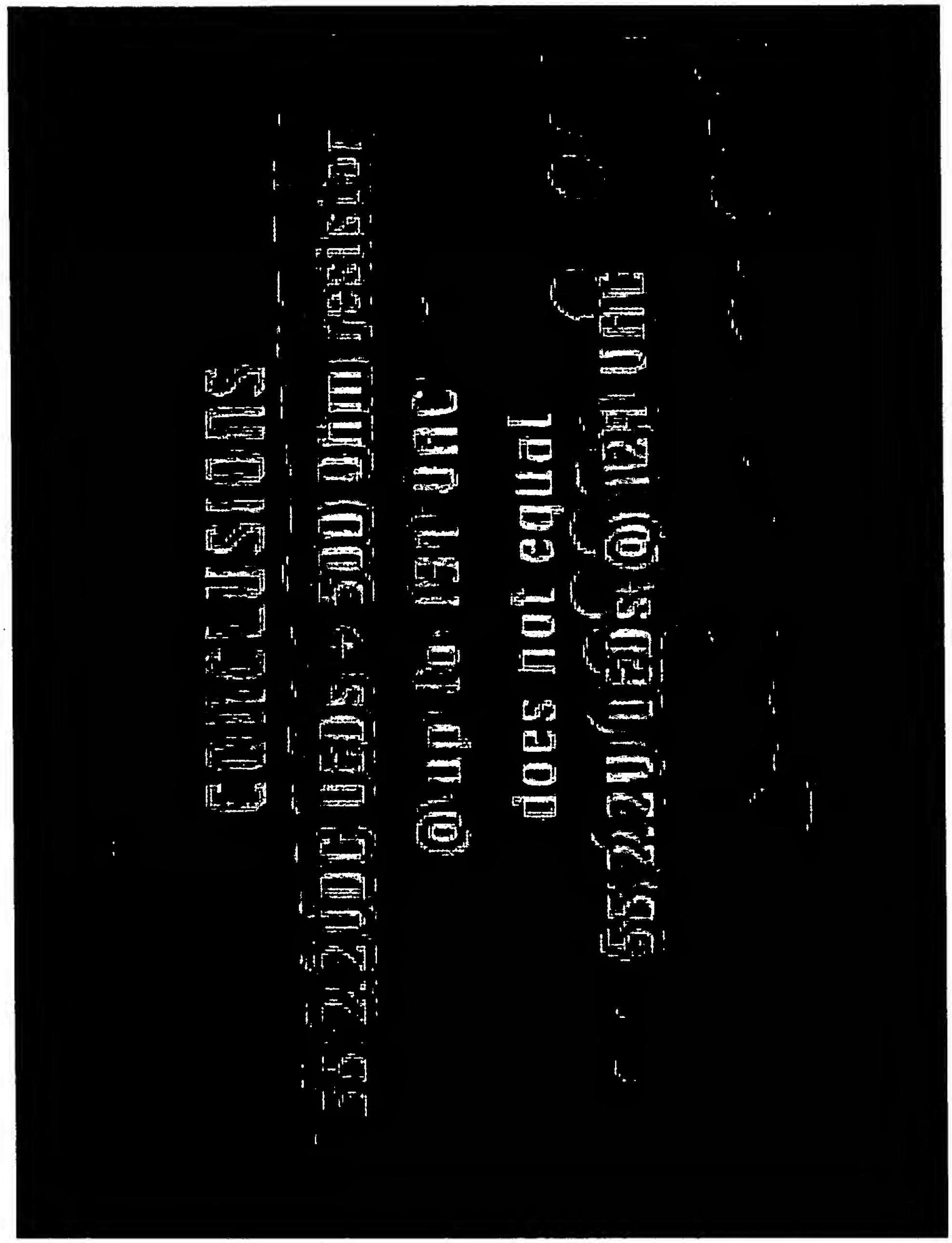
Duplicate the Yamuro circuit by building an equivalent circuit using U.S. AC source voltage...Experimental Circuit is identical to Yamuro's circuit since 55 2.2VDC LEDs + 500 Ohm resistor @ 120-130VAC (experiment) = 45 2VDC LEDs + 500 Ohm resistor @ 100VAC (Yamuro Example).

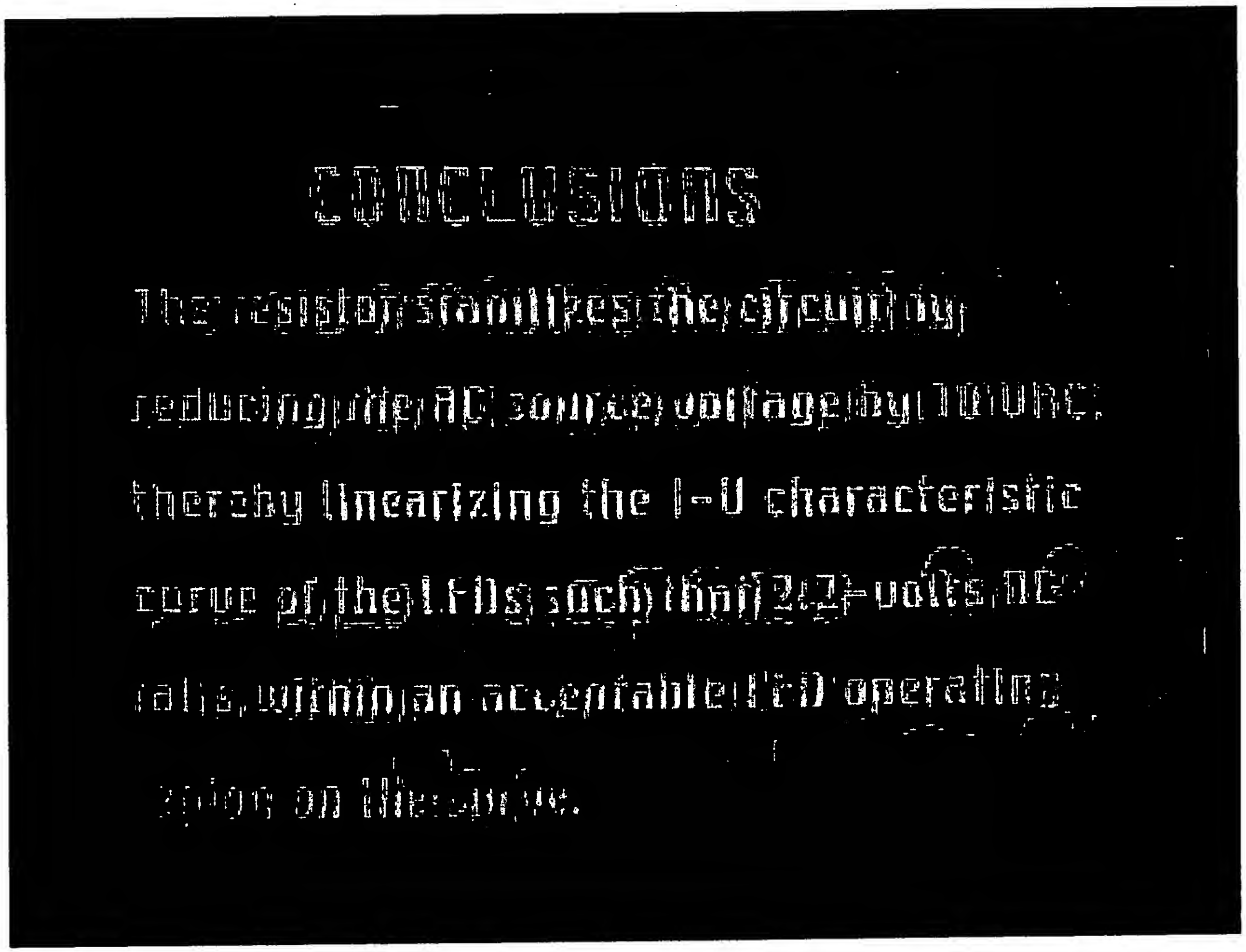

LEDs Used (Manufacturer's Specifications):
2.2 Vf DC at 20mA (typical)
Resistor Used: 500 Ohms
Assumes 120 VAC typical in the USA

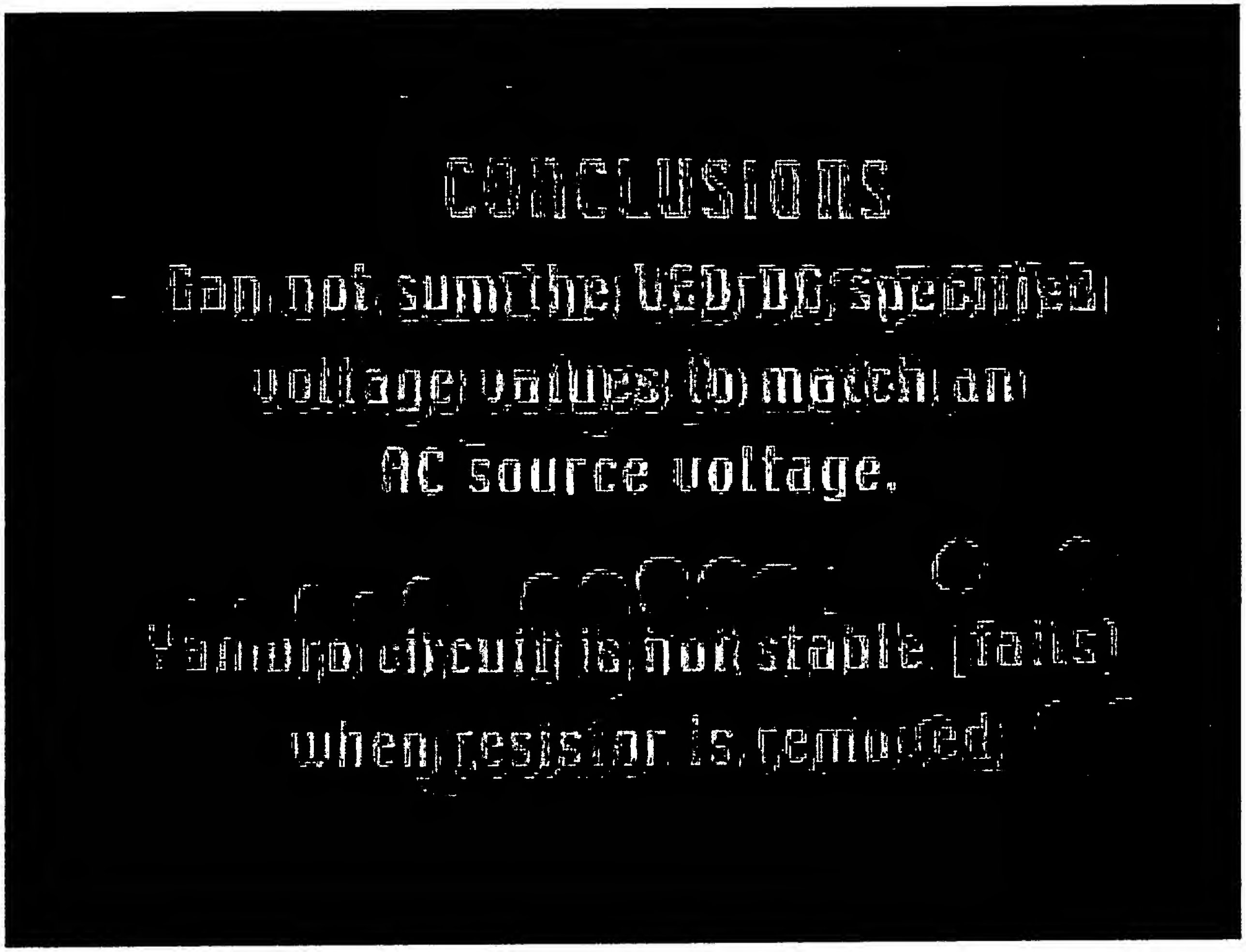


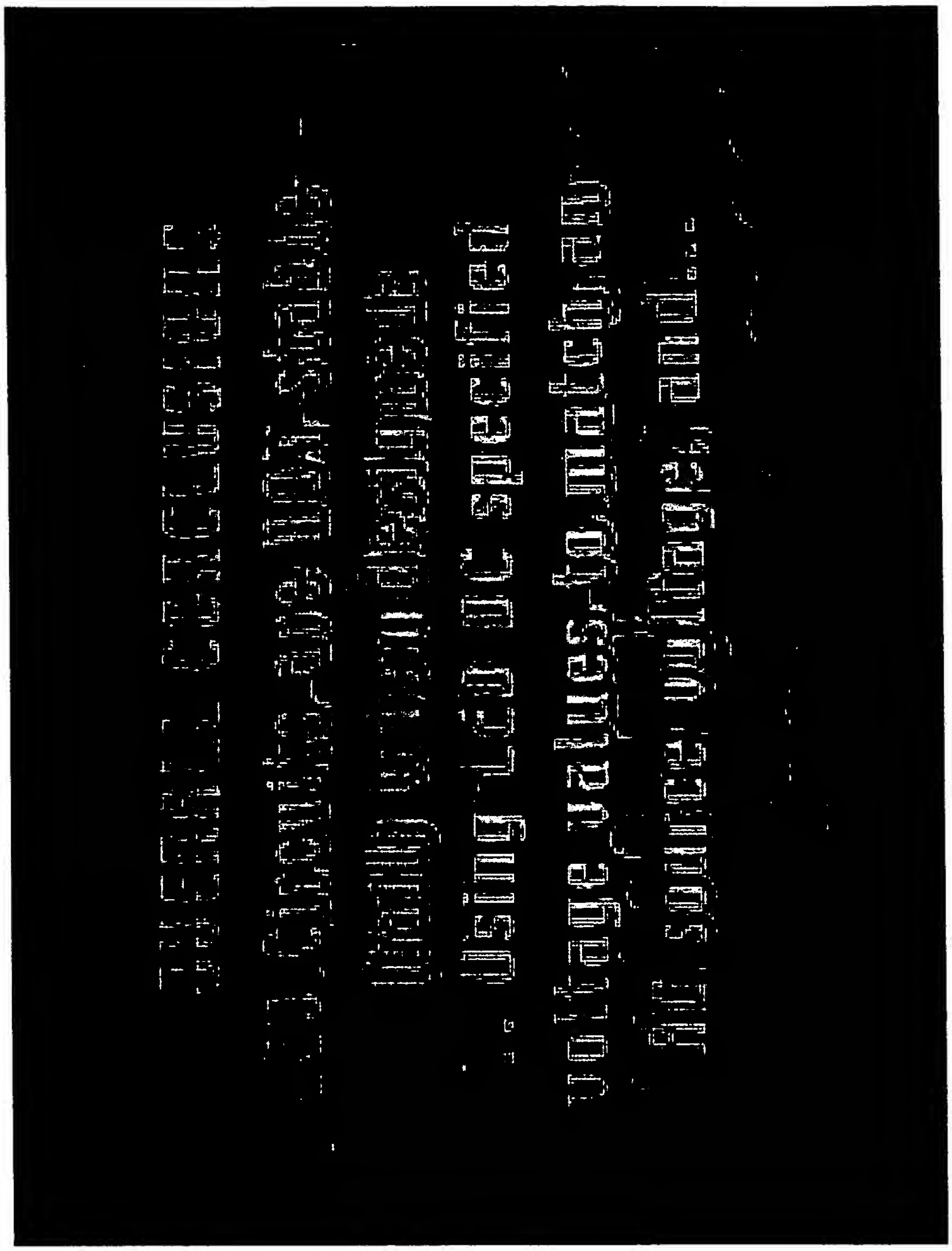



EXPERIMENT #4 RESULTS
Samuro circuit (resistor included)
is stable.
Examiner option circuit
(no resistor) is unstable
IT FAILS


CONCLUSIONS
35 2.2VDC LEDs + 500 Ohm resistor
does not equal


CONCLUSIONS
The resistor stabilizes the circuit by
reducing the AC source voltage by 10 VAC,
thereby linearizing the I-V characteristic
curve of the LEDs such that 2.2 volts DC
falls within an acceptable LED operating
region on the curve.


CONCLUSIONS
- Can not sum the LED/DC specified
voltage values to match an
AC source voltage.
Yamuro circuit is not stable (fails)
when resistor is removed.


OVERALL CONCLUSIONS
LED Circuits are NOT stable
1. Using LED DC specified
voltage values to match an
AC source voltage, and...

OVERALL CONCLUSIONS

LED Circuits are NOT stable (fail) when designed:

2. Without a resistor to linearize the I-V characteristics curve of the circuit such that the DC specified operating voltage of the LEDs intersect the curve at a stable operating region.

DAVID ALLEN:

Now, I would like to turn your attention once again to Dr. Mark Allen, Chief Technical Officer for Fiber Optic Designs, and Inventor. Dr. Allen possesses an earned Ph.D. in electrical engineering from the University of Pennsylvania and has worked as a high level research engineer for the past 15 years. Dr. Allen will explain the theories behind this invention.

DR. MARK ALLEN:

Let me explain the difference between AC and DC circuitry as applied to LEDs. LEDs are highly non-linear devices...that is, if one were to plot voltage versus current, one would end up with something different than a straight line. A resistor on the other hand...if I plot, say, current versus applied voltage here...is a straight line...it's a linear device. It follows Ohm's Law. Ohm's Law is $V = IR$...voltage equals current times resistance...so the resistance is the voltage divided by the current...so the slope here is related to the resistance. Actually, the slope of this straight line is simply one over the resistance, since I've plotted "I" versus "V."

An LED, on the other hand, is very different. If I were to plot "I" versus applied voltage...DC voltage...what would happen is that, for any voltage below some threshold voltage, the current is zero, including all negative voltages...the current is still zero. Above some threshold voltage, the current increases to some value such that the LED blows up...it breaks...so I'll call that V-max. This is Volts in voltages, uh, voltage in Volts, and this is current...I'll call it milliamps (mA). With LEDs, they're specified in DC...they're specified at a value where the current is considered to be stable at DC...where the device lasts a very long time. So it's the current that's significantly below this maximum current and its the current where the device is going to last long. Typically, a value of about 20mA is specified for LEDs. For LEDs that we use throughout the demonstration, the specified current is 20 mA. For these LEDs, the voltage that produces 20 mA on the average is called *the* voltage. That's a *DC* voltage.

In the applicant's design, we don't consider DC voltages because our circuit is an AC circuit. What happens in an AC circuit is that, if I look at the waveform, instead of having some constant value...this is voltage going along this direction...instead of having a constant DC value

which produces a DC current here, I have an AC value which goes up, and comes down, and goes up, and comes down...like a sinusoid. What happens here is that, if I were to plot the current as a function of time...in the same way that I plotted voltage...for DC I had a straight line here...this is "I"...it would produce a DC current. For AC voltage, like Okuno pointed out, the voltage...if the voltage looks like this...the current above some threshold turns on and it goes up and produces a very high spike, and it turns back off , and during the entire negative part of the cycle, the current is zero. So, there's two things of interest here. If this is one cycle, there is an average value of current that's produced for AC. Moreover, there is a peak value of current that's produced at AC.

What's done is our design is to pick values for maximum current and some average value of current...I-avg...and find the voltages by measurement. So, we know that the AC voltage is going to be somewhere above zero. So one would construct...and I'll do this in red to show the difference between this and DC...one would measure the voltage and find that it's another curve that looks like this. Now, if we had DC values here for the demonstration that we use, we have 2.0 Volts producing 20mA for DC. When we do AC measurements, we find that a lower value of average RMS voltage...that is...if I take this sinusoid, I square it and then I take the average of that...which is the square root of 2 over 2 times the peak...V-rms. This is the voltage that I plotted here, V-rms. For example in US household current, it's 110 Volts RMS...the peak value is 2 over the square root of 2...or the square root of 2...times the RMS value. So this would be 110 and this would correspond to 155 Volts. So what happens is, if I take a variable voltage AC source and dial in different voltages, and take measurements of average current, I'm going to produce a curve with little measurement points that looks like this...and what I want to do is find

out what kind of voltage in here produces what average -Amp current that I want...what average AC voltage produces what AC average current that I want.

Well, the guidelines show that AC current is not necessarily a value of 20mA. Even the value of 20mA that is specified is for certain LED longevity. It could have been designed at 25mA or 15mA. But somewhere around 20mA is what's recommended. HP, for example, recommends that AC average current is somewhat larger than that...it should be somewhere around, oh, 40mA. What's also shown in specifications is the current that these things generally blow up...the DC current...this is somewhere around 100 mA.

What we have done in our design is make sure that this average current right here is about 40mA, and this peak current is well less than 100...typically, a value of 90 mA is used. So one looks at this curve and finds what value of peak is produced and what value of average is produced. Well, for 40 mA, the average value is about 1.6 Volts. That's why we end up with a series block of 70 LEDs versus 50 LEDs or 55 LEDs. It's because 110 Volts divided by 1.6 Volts AC...these are both AC quantities...is equal to 70. Actually it's 69, so when we round it, we get about 70 LEDs. Notice that this number is the *minimum* number of LEDs that one would use...it's not a *maximum* number of LEDs.

In other designs in the past, the idea was to put a resistor in there to try to help linearize this function...to add resistance to this...so this function may move over a little bit and become more and more linear....that's adding in a resistor or some kind of impedance device. Instead, what we've done is remove this impedance device and concentrate on this curve...this AC current versus AC voltage curve here...and design the apparatus such that an average voltage of 1.6 Volts is produced for this particular design, where the specified voltage is 2.0 Volts DC. This is AC.

This is DC. One can notice from this curve...and I have drawn it in such a way...or at least I've tried...that, if one follows this curve up at 2.0 Volts, we're into the region of instability. That's precisely what we have demonstrated, in fact. If we use DC values for AC, what happens is that the current involved...the average AC current...is much higher than one would expect...and the system is driven so high, in fact, that the LED breaks down, and the circuit doesn't work...it's unstable.

In the past, the only method of alleviating this was to add resistance or impedence and linearize this curve...move it over. What we do is leave the curve the same but use an AC value for the voltage, rather than previously specified values for the voltage, and simply measure according to a criterion. Here, we've defined 40mA as being the average current...we measure what voltage produces that...the 1.6 corresponds to 40mA. If we use another value, say 30mA, we'd have yet a lower value of voltage, or, with 20mA, a lower value of voltage still.

3mm ROUND TYPE Electrical / Optical Characteristics at T_A = 25°C

PART NUMBER	CHIP		LENS COLOR	I_F = 20mA					
	MATERIAL	EMITTING COLOR		λ_p (nm)	V_F (v)		I_V (mcd)		2θ 1/2
				TYP.	TYP.	MAX.	MIN.	TYP.	(Deg.)
LT0371(2)-41-M1	GaAlAs / GaAs	RED	R.D.(W.D.)	660	1.7	2.2	70	110	56
LT0371(2)-41	GaAlAs / GaAs	SB RED	R.D.(W.D.)	660	1.7	2.2	110	180	56
LT0371(2)-41-UR	GaAlAs / GaAlAs	UR RED	R.D.(W.D.)	660	1.9	2.5	210	350	56
LT0321(2)-41-HE	GaP / GaP	HE GREEN	G.D.(W.D.)	567	2.1	2.6	20	30	56
LT0331(2)-41-M1	InGaAlP/GaAs	YELLOW	Y.D.(W.D.)	593	2.0	2.4	24	40	56
LT0331(2)-41-UR	InGaAlP/GaAs	UR YELLOW	Y.D.(W.D.)	593	2.0	2.4	70	120	56
LT0373(4)-41-M1	GaAlAs / GaAs	RED	W.C.(R.C.)	660	1.7	2.2	210	360	36
LT0373(4)-41	GaAlAs / GaAs	SB RED	W.C.(R.C.)	660	1.7	2.2	360	600	36
LT0373(4)-41-UR	GaAlAs / GaAlAs	UR RED	W.C.(R.C.)	660	1.9	2.5	700	1200	36
LT0323(4)-41-HE	GaP / GaP	HE GREEN	W.C.(G.C.)	567	2.1	2.6	70	110	36
LT0333(4)-41-M1	InGaAlP/GaAs	YELLOW	W.C.(Y.C.)	593	2.0	2.4	72	120	36
LT0333(4)-41-UR	InGaAlP/GaAs	UR YELLOW	W.C.(Y.C.)	593	2.0	2.4	240	400	36

5mm ROUND TYPE Electrical / Optical Characteristics at T_A = 25°C

PART NUMBER	CHIP		LENS COLOR	I_F = 20mA					
	MATERIAL	EMITTING COLOR		λ_p (nm)	V_F (v)		I_V (mcd)		2θ 1/2
				TYP.	TYP.	MAX.	MIN.	TYP.	(Deg.)
LT1871(2)-81-M1	GaAlAs / GaAs	RED	R.D.(W.D.)	660	1.7	2.2	108	180	36
LT1871(2)-81	GaAlAs / GaAs	SB RED	R.D.(W.D.)	660	1.7	2.2	180	300	36
LT1871(2)-81-UR	GaAlAs / GaAlAs	UR RED	R.D.(W.D.)	660	1.9	2.5	360	600	36
LT1821(2)-81-HE	GaP / GaP	HE GREEN	G.D.(W.D.)	567	2.1	2.6	60	100	36
LT1831(2)-81-M1	InGaAlP/GaAs	YELLOW	Y.D.(W.D.)	593	2.0	2.4	144	240	36
LT1831(2)-81-UR	InGaAlP/GaAs	UR YELLOW	Y.D.(W.D.)	593	2.0	2.4	240	400	36
LT18J1(2)-81-M1	InGaAlP/GaAs	ORANGE	O.D.(W.D.)	621	2.0	2.4	144	240	36
LT1873(4)-81-M1	GaAlAs / GaAs	RED	W.C.(R.C.)	660	1.7	2.2	360	600	22
LT1873(4)-81	GaAlAs / GaAs	SB RED	W.C.(R.C.)	660	1.7	2.2	600	1000	22
LT1873(4)-81-UR	GaAlAs / GaAlAs	UR RED	W.C.(R.C.)	660	1.9	2.5	1200	2000	22
LT1823(4)-81-HE	GaP / GaP	HE GREEN	W.C.(G.C.)	567	2.1	2.6	300	500	22
LT1833(4)-81-M1	InGaAlP/GaAs	YELLOW	W.C.(Y.C.)	593	2.0	2.4	250	420	22
LT1833(4)-81-UR	InGaAlP/GaAs	UR YELLOW	W.C.(Y.C.)	593	2.0	2.4	840	1400	22
LT18J3(4)-81-M1	InGaAlP/GaAs	ORANGE	W.C.(O.C.)	621	2.0	2.4	250	420	22
LT2K73(4)-81-M1	GaAlAs / GaAs	RED	W.C.(R.C.)	660	1.7	2.2	400	700	20
LT2K73(4)-81	GaAlAs / GaAs	SB RED	W.C.(R.C.)	660	1.7	2.2	700	1200	20
LT2K73(4)-81-UR	GaAlAs / GaAlAs	UR RED	W.C.(R.C.)	660	1.9	2.5	1400	2400	20
LT2K23(4)-81-HE	GaP / GaP	HE GREEN	W.C.(G.C.)	567	2.1	2.6	350	583	20
LT2K33(4)-81-M1	InGaAlP/GaAs	YELLOW	W.C.(Y.C.)	593	2.0	2.4	280	467	20
LT2K33(4)-81-UR	InGaAlP/GaAs	UR YELLOW	W.C.(Y.C.)	593	2.0	2.4	1000	1600	20

5 mm Round LEDs, T-1 3/4

Part Number EL-xxxxx	Chip			Lens Color	Vf(V)at If=20mA		Iv(mcd)			Angle $2\theta_{1/2}$
	Material	Emitted Color	λp (nm)		Typ.	Max.	at If=2mA Typ.	at If=20 mA Min.	at If=20 mA Typ.	
EL-333-2UBC	GaN/SiC	Blue	430	Water Clear	3.8	4.5	----	250	400	10
EL-333-2YGC/S530-A2	AlGaInP	Super Green	574	Water Clear	2.0	2.4	14	126	239	10
EL-333-2YGC/S530-A3	AlGaInP	Super Green	574	Water Clear	2.0	2.4	27	239	453	10
EL-333-2YGC/S530-A4	AlGaInP	Super Green	574	Water Clear	2.0	2.4	372	453	611	10
EL-333-2YGC/S530-A5	AlGaInP	Super Green	574	Water Clear	2.0	2.4	43	611	724	10
EL-333-2YGC/S400-A3	AlGaInP	Super Green	574	Water Clear	2.0	2.4	30	380	506	10
EL-333-2YGC/S400-A4	AlGaInP	Super Green	574	Water Clear	2.0	2.4	41	506	683	10
EL-333-2YGC/S400-A5	AlGaInP	Super Green	574	Water Clear	2.0	2.4	49	683	810	10
EL-333-2UYC/S530-A2	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	61	405	1013	10
EL-333-2UYC/S530-A3	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	89	945	1485	10
EL-333-2UYC/S530-A4	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	122	1350	2025	10
EL-333-2UYC/S530-A5	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	154	1620	2565	10
EL-333-2UYC/S530-A6	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	178	2025	2970	10
EL-333-2UYC/S400-A3	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	95	1003	1575	10
EL-333-2UYC/S400-A4	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	129	1432	2148	10
EL-333-2UYC/S400-A5	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	163	1719	2721	10
EL-333-2UYC/S400-A6	AlGaInP	Super Yellow	591	Water Clear	2.0	2.4	189	2148	3151	10
EL-333-2USOC/S530-A2	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	65	431	1077	10
EL-333-2USOC/S530-A3	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	95	1005	1579	10
EL-333-2USOC/S530-A4	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	129	1436	2154	10
EL-333-2USOC/S530-A5	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	164	1723	2728	10
EL-333-2USOC/S530-A6	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	190	2154	3159	10
EL-333-2USOC/S400-A3	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	108	1143	1795	10
EL-333-2USOC/S400-A4	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	147	1632	2448	10
EL-333-2USOC/S400-A5	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	186	1959	3101	10
EL-333-2USOC/S400-A6	AlGaInP	Super Sunset Orange	621	Water Clear	2.0	2.4	216	2448	3592	10
EL-333-2SURC/S530-A2	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	50	344	837	10
EL-333-2SURC/S530-A3	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	72	803	1204	10
EL-333-2SURC/S530-A4	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	98	1101	1639	10
EL-333-2SURC/S530-A5	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	122	1330	2041	10
EL-333-2SURC/S530-A6	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	148	1605	2465	10
EL-333-2SURC/S400-A3	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	81	905	1358	10
EL-333-2SURC/S400-A4	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	111	1241	1849	10
EL-333-2SURC/S400-A5	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	138	1500	2301	10
EL-333-2SURC/S400-A6	AlGaInP	[illegible]	632	Water Clear	2.0	2.4	167	1810	2780	10
EL-333-2USRC/S530-A2	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	38	298	628	10
EL-333-2USRC/S530-A3	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	51	532	851	10
EL-333-2USRC/S530-A4	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	64	639	1064	10
EL-333-2USRC/S530-A5	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	83	851	1384	10
EL-333-2USRC/S530-A6	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	102	1064	1703	10
EL-333-2USRC/S400-A3	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	57	596	954	10
EL-333-2USRC/S400-A4	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	72	716	1193	10
EL-333-2USRC/S400-A5	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	93	954	1551	10
EL-333-2USRC/S400-A6	AlGaInP	[illegible]	639	Water Clear	2.0	2.4	115	1193	1909	10
EL-333UWC/1B	GaN	Super Blue	----	Water Clear	3.6	4.0	----	500	1250	10
EL-333UWC	GaN	Super Blue	----	Water Clear	3.6	4.0	----	2200	3300	10

...Light 575NM

? Red

HE Green

4.8 × 2 = 9.6

3.8 × 2 = 7.6

7.6

113.6

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GaAsP/GaP YELLOW LED CHIPS
DEVICE NO. : ED-011HYH

1. SCOPE :

THIS SPECIFICATION APPLIES TO GaAsP/GaP YELLOW LED CHIPS, DEVICE NO. ED-011HYH.

2. STRUCTURE :

2-1. MESA TYPE : SMOOTH SURFACE.

2-2. ELECTRODES :

P (ANODE) SIDE : ALUMNIUM ALLOY OR GOLD ALLOY.

N (CATHODE) SIDE : GOLD ALLOY.

3. SIZE :

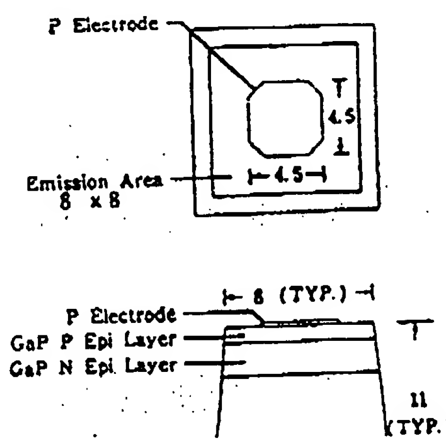
3-1. CHIP SIZE : 10 mils × 10 mils (0.254 mm × 0.254 mm).

3-2. PATTERN DRAWING : REFER TO THE ATTACHED DRAWING.

4. ELECTRO-OPTICAL CHARACTERISTICS (Ta = 25 °C)

PARAMETER	SYMBOL	CONDITION	MIN.	TYP.	MAX.	UNIT
FORWARD VOLTAGE	V_f	I_f=20mA		2.20	2.60	V
REVERSE CURRENT	I_r	V_r=5V			10	uA
LUMINOUS INTENSITY	I_V	I_f=20mA	3.0			mcd
SPECTRUM WIDTH OF HALF VALUE	$\Delta\lambda$	I_f=20mA		35		nm
WAVELENGTH	λ_P	I_f=20mA		589		nm
	λ_D			590		

PATTERN DRAWING
UNIT : mil



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Operational Considerations for LED Lamps and Display Devices

Application Note 1005

In the design of a drive circuit for an LED lamp, an LED light bar, or an LED 7-segment display, the objective is to achieve optimum light output, power dissipation, reliability, and operating life. The performance capabilities of each LED device are presented in the device data sheet. The data sheet contains tabular data and graphs that describe the optical and electrical characteristics of the LED device, and Absolute Maximum Ratings which are the maximum operating capabilities of the device. A thorough understanding of how to use this information is the basis for achieving an optimum design.

This application note presents an in-depth discussion of the use of the optical and electrical information contained in an LED device data sheet. Design examples for dc and pulsed operation are presented. The calculated results for each example are in **Bold Type** for identification.

Typical Data Sheet Information

Data sheets typically contain three tables of data. Usually for LED lamp devices the first table is titled **Device Selection Guide** or **Axial Luminous Intensity and Viewing Angle at T_A = 25°C** and presents the basic optical characteristics of the devices listed in the data sheet. The luminous intensity, I_v, both minimum and typical values, are listed in this table. This table is used as a device selection guide.

The next table is titled **Absolute Maximum Ratings at T_A = 25°C**, containing maximum peak, dc and average currents, maximum transient current, operating and storage temperature range, and the absolute maximum LED junction temperature. These are the maximum allowed operating conditions for all the devices in the data sheet.

The third table, titled **Electrical/Optical Characteristics at T_A = 25°C**, contains the electrical data, and some optical data, that are used to determine the operating conditions for the device. The forward voltage, V_F, and device thermal resistance, $R\theta_{J\text{-}PIN}$, used in operating condition calculations, are listed in this table.

The graphs usually contained in a lamp data sheet used to determine operational conditions are:

Figure 1. Relative Intensity vs. Wavelength. (not shown here)

Figure 2. Forward Current vs. Forward Voltage.

Figure 3. Relative Luminous Intensity vs. DC Forward Current.

Figure 4. Relative Efficiency vs. Peak Current. (This figure is not included on all data sheets.)

Figure 5. Maximum Forward DC Current vs. Ambient Temperature.

Figure 6. Maximum Average Current vs. Peak Forward Current.

Figure 7. Relative Luminous Intensity vs. Angular Displacement. (not shown here)

Design Criteria

The two criteria that establish the operating limits are the maximum

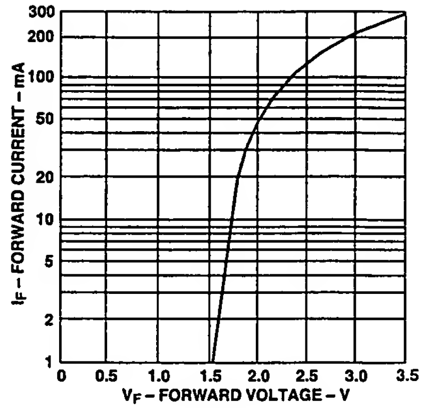

Figure 2. Forward Current vs. Forward Voltage.

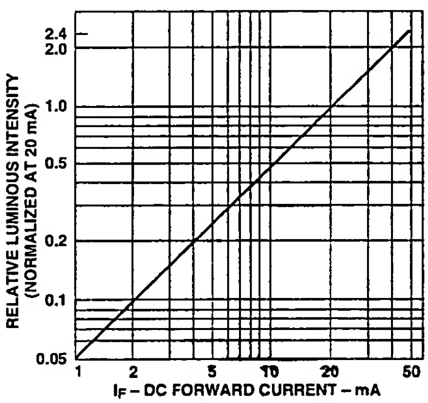

Figure 3. Relative Luminous Intensity vs. DC Forward Current.

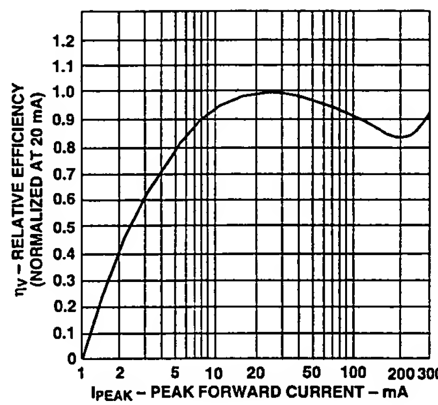

Figure 4. Relative Efficiency vs. Peak Forward Current.

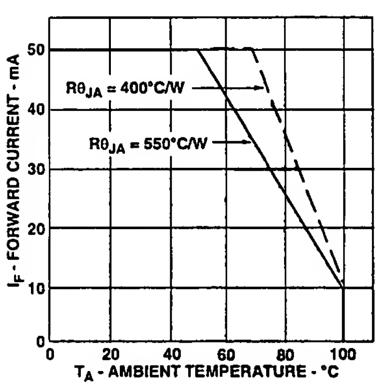

Figure 5. Maximum Forward DC Current vs. Ambient Temperature. Derating Based on T_JMAX = 110°C.

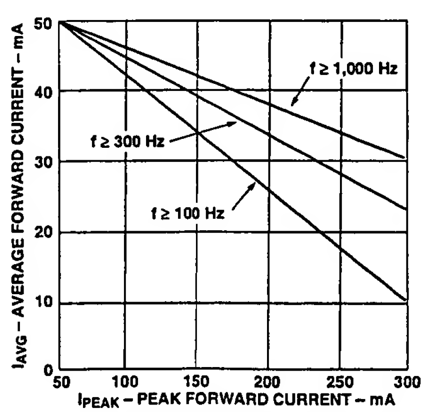

Figure 6. Maximum Average Current vs. Peak forward Current.

drive currents and the absolute maximum LED junction temperature, T_JMAX. The maximum drive currents have been established to ensure long operating life. The absolute maximum LED junction temperature is a device package limitation that must not be exceeded.

Thermal Resistance

The LED junction temperature, T_J(°C), is the sum of the ambient temperature, T_A(°C), and the temperature rise of the LED junction above ambient, ΔT_J(°C), which is the product of the power dissipated within the LED junction, P_D(W), and the thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}$(°C/W).

$$T_J = T_A + \Delta T_J$$
$$T_J = T_A + P_D \times R\theta_{J\text{-}A} \quad (1)$$

The cathode leads (pins) of a typical LED device are the primary thermal paths for heat dissipation from the LED junction to the surrounding environment. The exceptions are TS AlGaAs lamps, that use flip chip technology (anode die attach), where the anode lead is the primary thermal path. The data sheet lists the thermal resistance LED junction-to-pin, $R\theta_{J\text{-}PIN}$(°C/W), for each device type listed. This device thermal resistance is added to the pc board mounting assembly thermal resistance-to-ambient, $R\theta_{PC\text{-}A}$(°C/W), to obtain the overall thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}$(°C/W).

$$R\theta_{J\text{-}A} = R\theta_{J\text{-}PIN} + R\theta_{PC\text{-}A} \quad (2)$$

$R\theta_{J\text{-}A}$ is on a per LED chip basis for lamps, light bars, and 7-segment displays, and on a per device basis for displays with on-board ICs.

For reliable operation, it is recommended that the value of $R\theta_{PC\text{-}A}$ be designed low enough to achieve the lowest possible $R\theta_{J\text{-}A}$ to ensure the LED junction temperature does not exceed the absolute maximum value when the device is operated in the maximum surrounding ambient temperature.

Maximum Power Calculation

The maximum allowed power that may be dissipated within an LED junction, P_{MAX}, is determined by multiplying the maximum rated dc current by the forward voltage for that current, determined from Figure 2.

$$P_{MAX} = I_{DC}MAX \times V_F \quad (3)$$

Derating vs. Temperature

The drive current derating vs. temperature, Figure 5, is a function of drive current, T_JMAX, and $R\theta_{J\text{-}A}$. Typically derating curves are given from two ambient temperatures, T_A = 50°C (solid line) and 70°C (dashed line). The derating curves are lines of T_JMAX with slopes equal to the specific maximum $R\theta_{J\text{-}A}$ values indicated, intersecting the temperature axis at the maximum LED junction temperature point with zero current. Operation of the LED device at a particular drive current should be at or below a derating curve with a thermal resistance-to-ambient at or less than the maximum value indicated for that curve.

Current Limiting

An LED is a current operated device, and therefore, requires some kind of current limiting incorporated into the drive circuit. This current limiting typically takes the form of a current limiter resistor, R, placed in series with the LED. The forward voltage characteristic of Figure 2 is used to calculate the value of the series current limiter resistor.

$$R = \frac{V_{CC} - V_{SAT} - V_F}{I_{PEAK}} \quad (4)$$

Where:

V_{CC} = Power supply voltage.
V_{SAT} = Saturation voltage of driver transistor(s).
V_F = Forward voltage of the LED at I_{PEAK}.
I_{PEAK} = The peak drive current through the LED.

Light Output

The luminous intensity at T_A = 25°C for a particular dc drive condition is determined using the relative luminous intensity factor from Figure 3.

I_V (dc) = [I_V(25°C)] [Relative Intensity Factor] (5)

Where: I_V (25°C) is obtained from the data sheet.

For pulsed drive conditions, the time average luminous intensity is determined from the relative efficiency characteristic, η_V, presented in Figure 4. (Note: Not all data sheets include relative efficiency data.)

I_V (time average) = [I_V (25°C)] [I_{AVG}/I_F] [η_V] (6)

Where:

I_V (25°C) = Data sheet luminous intensity value.

I_{AVG} = The time average operating current.
I_F = The current where the data sheet luminous intensity is specified.
η_v = Relative efficiency factor for the peak drive current, I_{PEAK}.

The calculated luminous intensity value at T_A = 25°C can be adjusted for a different operating ambient temperature by the following exponential equation, and using the k factor for the specific LED.

$$I_V(T_A) = I_V(25°C)e^{[k(T_A - 25°C]} \quad (7)$$

LED	k
Standard Red	-0.0188/°C
High Efficiency Red	-0.0131/°C
Yellow	-0.0112/°C
Green	-0.0104/°C
DH AS AlGaAs	-0.0095/°C
TS AlGaAs	-0.0130/°C
AlInGaP	-0.0100/°C
TS AlInGaP	-0.0100/°C

Pulsed Operation vs. DC Operation

When operating an LED device under dc drive conditions, the LED junction temperature is a linear function of the dc power dissipation multiplied by $R\theta_{J\text{-}A}$. The light output is proportional to the dc drive current by the luminous intensity factor of Figure 3 and as expressed in Equation 5.

For best pulsed operation and overall light output performance, a rectangular current waveform with a refresh rate equal to or greater than 100 Hz is strongly recommended. Sinusoidal waveforms are not generally recommended, as the rms power will exceed that of a rectangular current waveform with the same peak current value. If a sinusoidal current waveform is used, the peak current should not exceed the maximum dc current rating. Sinusoidal waveforms produce less than two thirds the light output of an equivalent rectangular pulse, and at 50 or 60 Hz, are not fast enough to prevent observable flicker.

When operating an LED device in pulsed current mode, it is the peak junction temperature, not the average junction temperature, that governs the performance of the device. At refresh rates below 1000 Hz (the number of times per second a device is pulsed), the peak junction temperature is higher than the average junction temperature. As a result, the allowed time average currents for refresh rates between 100 Hz and 1000 Hz are less than those permitted at 1000 Hz, as can be seen by the 100 Hz and 300 Hz curves of Figure 6.

Design Steps

In order to determine the derated drive conditions from the data sheet for an elevated ambient temperature, the value for $R\theta_{J\text{-}A}$ must be determined. Once the value for $R\theta_{J\text{-}A}$ has been established, the required current derating can be determined for safe operation at the elevated temperature directly from Figure 5. The basic design steps are:

1. Determine $R\theta_{J\text{-}A}$.
2. Calculate the required value for $R\theta_{PC\text{-}A}$ for the pc board mounting configuration.
3. Determine the maximum allowable dc drive current for the operating ambient temperature.
4. Calculate the LED chip power dissipation to be sure it will not cause T_J to exceed the absolute maximum value.
5. Calculate the value of the current limiting resistor.
6. Determine the luminous intensity at 25°C and at the elevated ambient temperature.

The example calculations in this application note use representative data typically contained in LED lamp data sheets. The purpose of the calculations is to ensure reliable operation of an LED lamp when operated at an elevated ambient temperature. For the example calculations, a sample T-1 3/4 LED lamp is used, with 0.45 mm (0.018 in.) square leads and the following data sheet parameters:

Typical Luminous Intensity at 20 mA, I_V (25°C) = 2.0 cd (candela).
Maximum Peak Forward Current = 300 mA.
Maximum Average Forward Current = 30 mA (I_{PEAK} = 300 mA).
Maximum dc Forward Current = 50 mA.
Maximum LED Junction Temperature = 110°C.
$R\theta_{J\text{-}PIN}$ = 260°C/W

DC Design Example

In this example, the operating ambient temperature is assumed to be T_A = 60°C.

Step 1. For this example, the value for $R\theta_{J\text{-}A}$ has been established to be 500°C/W.

Step 2.
From Equation 2:
$R\theta_{PC\text{-}A}$ = (500 - 260°C/W)
$R\theta_{PC\text{-}A}$ = **240°C/W**

The pc board mounting assembly should be designed to provide this value of thermal resistance to ambient, or less, for reliable operation of the LED device.

Step 3.
From Figure 5, the following are determined:
1) $R\theta_{PC\text{-}A}$ at 500°C/W is less than the maximum $R\theta_{PC\text{-}A}$ shown for the solid line derating curve.
2) The maximum allowable dc current at T_A of 60°C = **42 mA**.

Step 4.
Calculation of the power dissipation for 42 mA drive current using Equation 3.
From Figure 2, V_F (42 mA) = 1.95 volts.
P(W) =
(0.042 A) (1.95 V) = 0.082 W
P(W) = **82 mW**

Using Equation 1 for LED junction temperature:

T_J = 60°C + (0.082 W) (500°C/W)
T_J = **101°C**, less than the maximum allowable 110°C.

Step 5.
Equation 4 is used to calculate the value of the current limiting resistor. A 5 volt power supply is used. One switching transistor is used to drive the LED lamp with a saturation of 0.1 volts.

$$R = \frac{5.0\ V - 0.1\ V - 1.95\ V}{0.042\ A}$$

R = **70 Ω**

Resistor power rating should be 2x the actual power dissipation:

$P_R = I^2 \times R = (0.042\ A)^2 \times 70\ \Omega$
P_R = **0.123 W**

Thus, use a 1/4 watt 70 Ω resistor.

Step 6.
The luminous intensity at T_A = 25°C is determined from Figure 3 and Equation 5:

From Figure 3, the relative luminous intensity factor at 42 mA = 2.0.

I_V (25 °C) = (2.0 cd) (2.0)
I_V (25 °C) = **4.0 cd**

At the operating temperature of 60°C, the luminous intensity is calculated using Equation 7 and the appropriate k value. For this example, k = -0.0130/°C

I_V (60°C) =
(4.0 cd) $e^{-0.0130/°C(60 - 25°C)}$
I_V (60°C) = (4.0 cd) (0.634)
I_V (60°C) = **2.54 cd**

DC parameter summary:
T_A = 60°C
$R\theta_{PC\text{-}A}$ = 240°C/W
I_F (dc) = 42 mA
T_J = 101°C
R = 70 Ω, 1/4 W
I_V (25°C) = 4.0 cd
I_V (60°C) = 2.54 cd

Pulsed Mode Design Example
In this example, T_A = 50°C, and the above LED lamp is to be pulsed with a refresh rate of 1000 Hz at 200 mA peak drive current.

Steps 1 and 2. The $R\theta_{J\text{-}A}$ and $R\theta_{PC\text{-}A}$ values are the same as determined in the above DC Design Example.

Step 3.
From Figure 6, at a refresh rate of 1000 Hz and I_{PEAK} of 200 mA, the maximum allowable time average current, I_{AVG}, = **38 mA**.

The on-time duty factor, DF is:
DF = I_{AVG} / I_{PEAK}
DF = 38 mA / 200 mA = 0.190
DF = **19.0%**

Step 4.
From Figure 2, V_F (200 mA) = 2.8 volts. The time average power is:

P = I_{PEAK} x V_F (I_{PEAK}) x DF
P = (0.200 A) (2.8 V) (0.190)
P = **0.106 W**

Using Equation 1 for LED junction temperature:
T_J =
50°C + (0.106 W) (500°C/W)
T_J = **103°C**, less than the maximum allowable 110°C.

Step 5.
At 200 mA, the driver transistor saturation is 0.2 volts.

$$R = \frac{5.0\ V - 0.2\ V - 2.8\ V}{0.200\ A}$$

R = **10 Ω**

Resistor power rating should be 2x the time average power dissipation:

$P_R = (I_{PEAK})^2 \times R \times DF$
$= (0.200\ A)^2 (10\ \Omega) (0.190)$
P_R = **0.076 W**

Thus, use a 1/4 watt 10 Ω resistor.

Step 6.
The time average luminous intensity at T_A = 25°C is determined using Equation 6 and the relative efficiency factor from Figure 4.

From Figure 4,
η_V (200 mA) = 0.82.
I_V (25°C) =
[2.0 cd] [38 mA/20 mA] [0.82]
I_V (25°C) = [2.0 cd] [1.56]
I_V (25°C) = **3.12 cd**

I_V (50°C) =
(3.12 cd) $e^{-0.0130/°C(50 - 25°C)}$
I_V (50°C) = (3.1 cd) (0.723)
I_V (50°C)) = **2.26 cd**

Pulsed parameter summary:
T_A = 50°C
$R\theta_{PC\text{-}A}$ = 240°C/W
I_{PEAK} = 200 mA
I_{AVG} = 38 mA
f = 1000 Hz; DF = 19.0%
T_J = 103°C
R = 10 Ω, 1/4 W
I_V (25°C) = 3.12 cd
I_V (60°C) = 2.26 cd

DC Operation is Better than Pulsed Operation for Light Output

It is always better to drive an LED device with a high dc current to obtain the necessary light output to be viewed by a human observer than to pulse drive the LED. Using a high peak current and a low duty factor to pulse drive an LED device produces less time average light output than by using a high dc drive current.

There are only two reasons for pulse driving an LED device:
1) To strobe an LED array to form messages of changing characters or symbols to be viewed by human observers.
2) To obtain a peak pulse of light to be received by a photodetector in a non-visual emitter/detector application. In this case, the high peak pulse of light produces a high peak photocurrent output from the photodetector.

Operation Without Current Derating
LED lamp and display devices may be operated in elevated ambient temperatures without current derating only when the pc board mounting configuration is designed for a sufficiently low thermal resistance-to-ambient. The criterion is that the LED junction temperature must not exceed the T_JMAX value for the device. This low thermal resistance design may include such items as a maximum metalized pc board and possible heat sinking to ensure adequate heat dissipation. Operation above the Absolute Maximum Current Ratings is not recommended.

The necessary thermal resistance requirements for operation without current derating are calculated for the maximum power dissipation using the Absolute Maximum DC Current.

1. Calculate the maximum power dissipation, if not provided on the data sheet.

2. Using Equation 1, calculate the allowable ΔT_J rise above the elevated ambient temperature.

3. Calculate the required thermal resistance LED junction-to-ambient, $R\theta_{J\text{-}A}$.

$$R\theta_{J\text{-}A} = \Delta T_J / P_{MAX} \qquad (8)$$

4. Calculate the allowable thermal resistance pc board-to-ambient using Equation 2.

Using the above sample LED lamp, the following example calculations determine the thermal resistance requirements for operating at T_A = 80°C without dc current derating.

Step 1.
V_F (50 mA) = 2.05 V.

From Equation 3:
P_{MAX} = (0.050 A) (2.05 V)
P_{MAX} = **0.103 W**

Step 2.
From Equation 1:
ΔT_J = 110°C - 80°C
ΔT_J = **30°C**

Step 3.
Using Equation 8:
$R\theta_{J\text{-}A}$ = 30°C / 0.103 W
$R\theta_{J\text{-}A}$ = **291°C/W**

Step 4.
From Equation 2:
$R\theta_{PC\text{-}A}$ = 291°C/W - 260°C/W
$R\theta_{PC\text{-}A}$ = **31°C/W**

To obtain this low a value for the pc board thermal resistance-to-ambient necessitates the use of a maximum metalized pc board, may require special heat sinking attached to the device leads, and forced air cooling. This means considerable cost is added to the design to allow for operation at 80°C without current derating.

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